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Short-Circuit Current of Induction Motors and Generators

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There has been a rather prevailing opinion that a sudden short circuit of an induction generator would not cause a serious initial rise in current such as occurs in synchronous generators. This has led to the proposal of the use of such machines as a partial solution of the short-circuit problem on a-c. systems. Theoretical considerations and experimental data given in the paper show that, on the contrary, there is in the induction generator, just as in the synchronous machine, a serious initial rush of current which is limited only by the leakage reactance of the machine. The only difference is that the transient is shorter in the induction machine, and the current dies down, of course, to zero instead of to the sustained value which occurs in an excited synchronous generator.

THE problem of short circuits on alternating-current systems is ever becoming more pressing. The calculation of the short-circuit current of the generating apparatus is therefore of utmost importance. This calculation for synchronous machines has been covered in an Institute paper[1] presented in 1918. The present paper deals with the induction machine. This study was prompted by the suggestion, which has now and then been proposed, that the installation of induction generators might possibly be a partial solution of the short-circuit problem. The basis for the suggestion was, of course, the supposition that the initial short-circuit current of this type of machine was negligible. This supposition rested on the idea that, unlike the synchronous machine, the induction generator has no permanent excitation, and therefore when the terminals are short-circuited and all electrical connection thus removed, the existing small current will die out exponentially. A study of the problem however, indicated that this was not the case. Subsequent tests given herewith confirm that view and show that on large induction generators serious initial short-circuit currents may be expected, just as on synchronous machines.

From a search of the literature it appears that very little has been published on this subject. In 1910 Messrs. Spooner and Barnes[2] published an article on "The Induction Generator," giving the results of comparative short-circuit tests on synchronous and induction generators. Quoting from the article, "Theory would indicate that a short circuit would be equivalent to a withdrawal of the exciting current from the induction generator and hence it would cease to deliver energy. The accompanying oscillogram, which is a typical current record, shows this to be the case." These tests, however, were made on a small machine (10 h. p.) of relatively high resistance and therefore are not, as will be pointed out later, representive of conditions that would exist in large induction generators. In the same year a paper[3] by G. W. Meyer stated that, "If induction generators are used, a short circuit in the line does not cause an abnormal rise of current in these machines. They simply cease to generate."

The present investigation, however, shows that the sudden short circuit of an induction generator or motor, like that of a synchronous machine, is initially

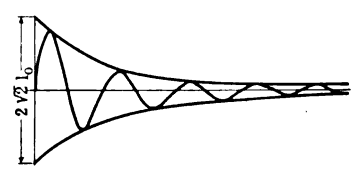


Fig. 1—Diagram Showing Method of Determining the Short-Circuit Current

many times normal, and depends in value upon the total leakage reactance. Unlike the synchronous machine, there is no "sustained" current. Instead the current decreases in a few cycles, from the high value existing in the moment of short circuit to zero. This is shown in Fig. 1.

The comparison of the *initial* short-circuit currents of induction and synchronous machines is really a comparison of practically identical phenomena. In either case, the relation of the flux in the machines to the stator and rotor windings is in fundamental respects the same. In either, the poles of the magnetic flux rotate at synchronous speed with respect to the stator windings, and at the same time the flux is linked

To be presented at the Midwinter Convention of the A. I. E. E., New York, February 16-18, 1921.

1. "Reactance of Sychronous Machines and its Application," by R. E. Doherty and O. E. Shirley, Trans. A. I. E. E., 1918, Vol 37, Part 2, page 1209.

2. *Electrical World*, February 24, 1910.

3. "Short Circuits in Alternating-Current Mains: Their Reaction on Generators and Means for Diminishing their Harmful Effects," by G. W. Meyer in *Elektrotechnische Rundschau*, October 19, November 3, November 24, 1910.

with the closed rotor winding. The fact that in normal operation the flux of the induction machine "slips" with respect to the rotor winding, does not change the circumstance that it is nevertheless at all instants linked with the closed winding. Neither does the fact that the rotor winding of the synchronous machine has direct-current excitation whereas that of the induction machine has not, alter in a fundamental way the conditions which determine the initial current; although it does, of course, determine altogether the difference between the final values.

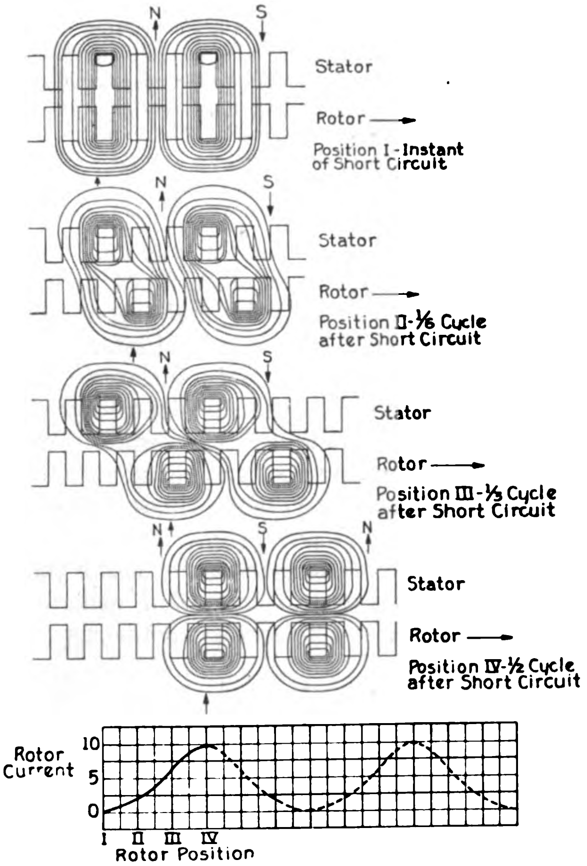


FIG. 2—DISTRIBUTION OF PRIMARY AND SECONDARY FLUX FOR DIFFERENT POLE POSITIONS AFTER SHORT CIRCUIT

It follows from Lentz's Law that *a closed electric circuit, without resistance, must persist magnetically in the same condition as at the instant of closing; that is, must contain as long as it is closed, the same number of magnetic interlinkages.* While both stator and rotor windings of course do contain some resistance, it is yet small enough to make possible at least a qualitative study of initial conditions on the assumption that the resistance is zero; and from that, one may form an idea of the modification which a small value or resistance would involve.

Suppose an induction motor is running at full voltage no load, and that the terminals of the stator winding are suddenly short-circuited. For convenience assume that when this happens, no flux is linked with the stator coils. Then, by Lentz's Law and the assumption of zero resistance, no flux can enter those coils. The rotating flux attempting to enter the winding causes sufficient current to flow in the winding, *i. e.* sufficient m. m. f., to force the flux out, *i. e.*, tends to "kill" the magnetic field. But this field, being linked with the closed rotor circuit, can not die out. It can not decrease at all, since doing so would involve a change of interlinkages. Neither could the flux cease rotation for the same reason. Therefore, since the flux can not enter the stator and yet must emanate from the rotor surface and remain linked with the rotor coils, it follows that it must pass through the leakage paths, largely along the air gap and tooth tips between the stator and rotor winding and return to the rotor. Now the m. m. f. required to maintain normal flux in the leakage paths is greater than the m. m. f. of normal current in the ratio of normal flux to the leakage flux produced by normal current. Hence the m. m. f. at short circuit depends directly upon the leakage reactance of the machine.

It is clear that the stator current, generated by the rotating flux, is alternating, whereas the rotor current, being that required to maintain a direct flux, is itself direct.

The foregoing assumed that the stator interlinkages were zero when the short circuit occurred. Actually, in a polyphase machine, the entire flux is linked at all instants with some phase or phases. Hence the stator interlinkages must always be the same, *i. e.*, those due to normal flux regardless of the instant of short circuit. This means that there must always be two sets of magnetic poles of practically equal intensity. See Fig. 2. One, just mentioned, linked with the closed stator winding and therefore stationary in space; the other, described in the foregoing, linked with the rotor winding and therefore rotating in space. And just as the latter causes direct current in the rotor and alternating current in the stator, so does the former cause direct current in the stator and alternating current in the rotor. Thus the total current in either the stator or the rotor is the resultant of an alternating and a direct component.

Obviously these components must be roughly of the same magnitude, since the m. m. f. in either case is that required to maintain normal flux in the leakage paths. Actually the a-c. component of the stator is less than the d-c. component because the flux linked with the rotor (which causes the a-c. component in the stator) is slightly less than the flux linked with the stator (which causes the d-c. component in the stator).

It is clear from the above considerations, that, assuming the same leakage inductance, the initial value of short-circuit current will be the same in a given machine whether it is operating as induction motor, or as a synchronous motor with direct-current excitation in the secondary winding. There would, of course, be some difference in the leakage inductance when operated as an induction machine and when operated as a synchronous machine.

The effect of shaft load upon the value of the short-circuit current is small. The primary flux per pole is a fixed value for a given voltage. At no load all of this flux, except 5 per cent or so, is linked also with the secondary pole, the 5 per cent being the leakage due to the exciting current. Under load, the per cent by which the remaining 95 per cent linked with the rotor, is reduced is not in direct proportion to the increase in the stator current on account of the phase difference between the

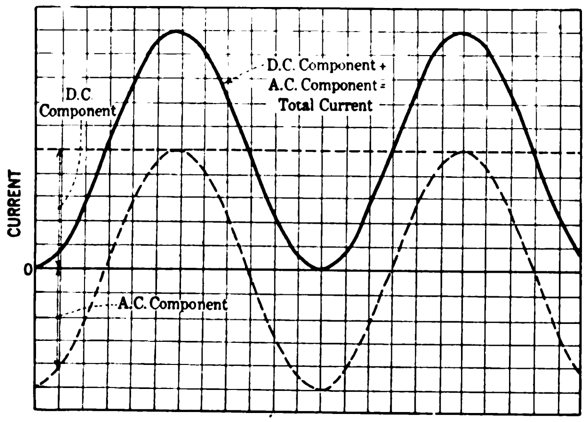


FIG. 3—CURVE SHOWING THE SUDDEN SHORT-CIRCUIT CURRENT OF INDUCTION MOTOR IF IT IS ASSUMED THAT THE RESISTANCE IS ZERO

exciting current and the load current, and therefore between leakage fluxes produced by those currents. In other words, the primary flux per pole is unchanged, the rotor flux is further reduced by 5 per cent, leaving, say, 90 per cent. Thus the primary d-c. component will be the same, the primary a-c. component and both components of the secondary current will be less by about 5 per cent. Hence the difference in the total current is small.

Assuming no resistance, the general shape of the short-circuit current wave would be as shown in Fig. 3.

With resistance, which is present in every case, the flux linked with the two members will die out as an exponential function of time. Such a short-circuit current wave is plotted in Fig. 4. In this case the d-c. component of the primary is:

$$i_1 \text{ d-c.} = \sqrt{2}\, I_{01}\, \epsilon^{-\frac{r_1}{L_0} t}$$

and the a-c. component is

$$i_1 \text{ a-c.} = -\sqrt{2}\, I_{01}\, \epsilon^{-\frac{r_1}{L_0} t} \cos \omega t$$

Then the total primary current is

$$i_1 = i_1 \text{ d-c.} + i_1 \text{ a-c.} = \sqrt{2}\, I_{01}\, \epsilon^{-\frac{r_1}{L_0} t} (1 - \cos \omega t)$$

Where,

i_1 = instantaneous primary current

I_{01} = r. m. s. of the initial value of a-c. component

$$\text{in primary} = \frac{\text{(normal voltage per phase)}}{\text{(impedance per phase)}}$$

$$= \frac{E}{\sqrt{r^2 + X^2}}$$

r = total resistance per phase = $r_1 + r_2$

r_1 = resistance per phase of primary

r_2 = resistance per phase of secondary reduced to primary terms

X = total leakage reactance per phase (primary terms)

$L_0 = X \div 2 \pi f$

The above equations apply when the ratio $r_1/L_0 = r_2/L_0$, that is, when $r_1 = r_2$.

Resistance does not appreciably affect the initial value of short-circuit current since the resistance is usually small compared with the reactance. For example in a case where $r = 5$ per cent and $X = 20$ per cent the error due to neglecting r in the impedance would be only 3 per cent, which is negligible. Resistance does, however, affect the duration of the short-circuit current, since, in this case, r appears as a factor of direct proportionality in the attenuation factor r/L.

In general, the primary and secondary members are magnetically very similar. That is, the ratio L/r is very nearly the same for either member. Hence the two fluxes die out at about the same rate. A conception of this rate can be had from the following illustration. Take, for example, a 60-cycle machine with 2.5 per cent resistance loss in each member, (*i. e.* 2.5 per cent resistance drop in each member at

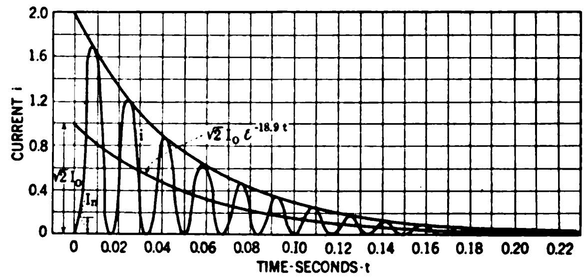


FIG. 4—CALCULATED CURVE OF THE SUDDEN SHORT-CIRCUIT CURRENT OF AN INDUCTION MOTOR

Equation of short-circuit current

$$i = \sqrt{2}\, I_0 \,(E^{-18.9t} - E^{-18.9t} \cos \omega t) = \sqrt{2}\, I_0\, E^{-18.9t} (1 - \cos \omega t)$$

Assumed Constants

	Stator	Rotor
	r = 1 per cent	r = 1 per cent
Total	x = 20 per cent	
	$\frac{r}{L_0} = 18.9$	$\frac{r}{L_0} = 18.9$

I_N = normal rated current

$$I_0 = \frac{100}{x} I_N = 5\, I_N$$

normal current) and a leakage reactance of 20 per cent. Then the time constant is,

$$\frac{L_0}{r} = \frac{\frac{20}{2 \pi f}}{2.5} = \frac{20}{2 \pi \times 60 \times 2.5}$$

$$= 0.021 \text{ second}$$

which means that in four times 0.021 second, or 0.084 second, that is five cycles, the flux, and therefore the current, will have practically died out. It is

very important to note that at one-half cycle (0.0083 sec.) when the current reaches the maximum peak (that is, when assuming no transient, sufficient m. m. f. would necessarily exist to support twice

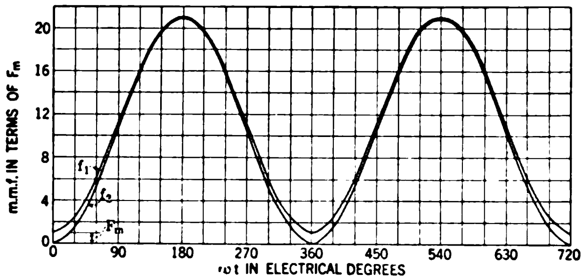


FIG. 5—CALCULATED CURVE OF M. M. F. AT SHORT CIRCUIT OF A POLYPHASE INDUCTION MOTOR

Primary m. m. f. $= f_1 = \dfrac{F_m}{\dfrac{P_1 P_2}{P_m^2} - 1} \left[\dfrac{P_1 P_2}{P_m^2} - \cos \omega t \right]$

Assumed Constants

$$\frac{P_m}{P_1} = \frac{P_m}{P_2} = 0.95$$

Secondary m. m. f. $= f_2 = F_m \dfrac{P_1}{P_m} \left[\dfrac{1 - \cos \omega t}{\dfrac{P_1 P_2}{P_m^2} - 1} \right]$

normal flux in the leakage paths) the flux has already decreased to 70 per cent of its initial value. This is important because if the resistance is less, say 1 per cent, as in the case of large induction generators, the

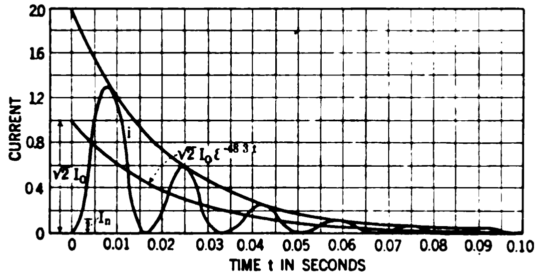


FIG. 6—CALCULATED CURVE OF THE SUDDEN SHORT-CIRCUIT CURRENT OF A 150-H. P. THREE-PHASE, 60-CYCLE, 720-REV. PER MIN., 440-VOLT INDUCTION MOTOR. SEE TEST CURVE IN FIG. 7.

Equation of short-circuit current

$$i = \sqrt{2}\, I_0 \,(\epsilon^{-48.3t} - \epsilon^{-48.3t} \cos \omega t)$$
$$= \sqrt{2}\, I_0 \,\epsilon^{-48.3t} (1 - \cos \omega t)$$

Design Constants

	Stator		Rotor
	r = 2.1 per cent		r = 2.1 per cent
Total	x = 16.5 per cent		
	$\dfrac{r}{L} = 48.3$		$\dfrac{r}{L} = 48.3$

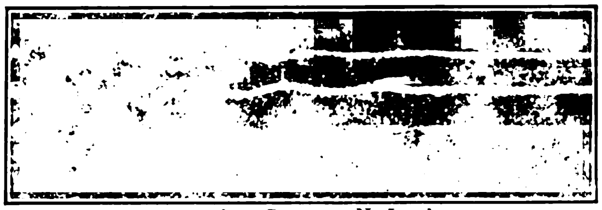
I_n = normal rated current

$$I_0 = \frac{100}{x} I_n = 6.06\, I_n$$

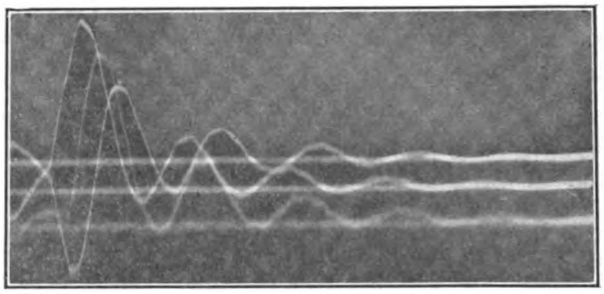
flux, and therefore the current at this critical instant, would be higher. Moreover, the leakage paths would be more nearly saturated, thus causing an additional increase in current. Using 1 per cent resistance in the above illustration, the flux at the end of one-half cycle would be only 85 per cent instead of 70 per cent initial value. Such a case is plotted in Fig. 4.

In connection with this investigation four conditions of short circuit have been considered. The calculated curves of m. m. f. are plotted for each case and accompanying oscillograms show the actual current curves for two cases. Equations are developed

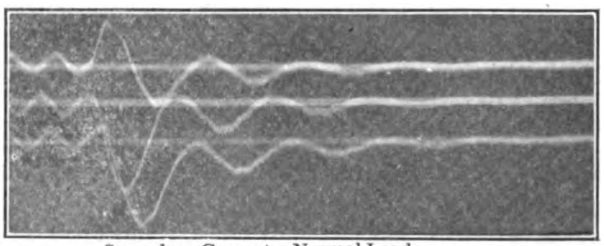
Primary Current—No Load.



Secondary Current—No Load.



Primary Current—Normal Load.



Secondary Current—Normal Load.

FIG. 7—OSCILLOGRAMS OF THE SHORT-CIRCUIT CURRENT OF AN INDUCTION MOTOR

150-h. p., three-phase, 60-cycle, 720-rev. per min., 440-volt three-phase short circuit at 440 volts.

in the Appendix for each of the cases and are as follows:

Case I. Polyphase short circuit on a polyphase induction motor or generator. The equation for the primary m. m. f. is,

$$f_1 = \frac{F_m}{\dfrac{P_1 P_2}{P_m^2} - 1} \left[\frac{P_1 P_2}{P_m^2} - \cos \omega t \right] \quad (9)$$

and for the secondary m. m. f. is,

$$f_2 = F_m \frac{P_1}{P_m} \left[\frac{1 - \cos \omega t}{\dfrac{P_1 P_2}{P_m^2} - 1} \right] \quad (10)$$

Fig. 5 shows the calculated curves plotted from these equations.

This case of a polyphase short circuit is the most important and the equations have, therefore, been reduced to terms of current instead of m. m. f., and the effect of resistance is taken into account by introducing the transient factor. The equation for the primary current is,

$$i_1 = \sqrt{2}\, I_{01}\, \epsilon^{\frac{r_1}{L_0}t}\ (1 - \cos\omega t) \qquad (26)$$

and for the secondary current is,

$$i_2 = \sqrt{2}\, I_{02}\, \epsilon^{-\frac{r_2}{L_0}t}\ (1 - \cos\omega t) \qquad (27)$$

The curve in Fig. 6 is plotted from equation (26) and Fig. 7 shows the oscillogram of the current from test.

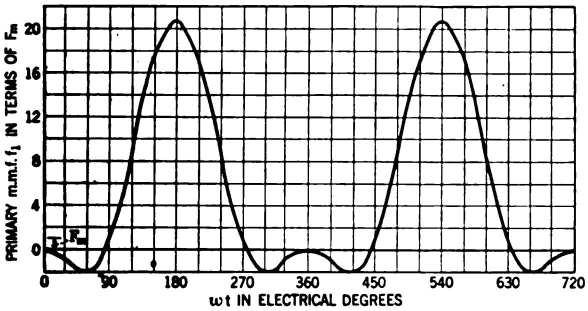


FIG. 8—CALCULATED CURVE OF PRIMARY M. M. F. AT SUDDEN SHORT CIRCUIT OF A POLYPHASE INDUCTION MOTOR HAVING THE SECONDARY EXCITED WITH THE DIRECT CURRENT.

$$f_1 = F_m \frac{P_m}{P_1}\left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1}\left\{\frac{P_1 P_2}{P_m^2}\cos\omega t - \frac{1}{2}(1 + \cos 2\,\omega t)\right\}\right]$$

Assumed Constants

$$\frac{P_m}{P_1} = \frac{P_m}{P_2} = 0.95$$

Case II. Polyphase short circuit on a polyphase induction machine having one phase of the rotor excited with direct current, that is, operating as a synchronous machine. The equation for the primary m. m. f. is,

$$f_1 = F_m \frac{P_m}{P_1}\left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1}\left\{\frac{P_1 P_2}{P_m^2}\cos\omega t - 1/2\,(1 + \cos 2\,\omega t)\right\}\right] \qquad (32)$$

and for the secondary m. m. f. is,

$$f_2 = F_m \frac{\frac{P_1 P_2}{P_m^2} - \cos\omega t}{\frac{P_1 P_2}{P_m^2} - 1} \qquad (31)$$

These equations are plotted in Fig. 8 and Fig. 9. The test curve is shown in Fig. 10. The difference between the test curve for f_1 and the curve of stator current in Fig. 10 can probably be accounted for by the fact that the rotor resistance is increased by a rheostat and an exciter in the circuit. This causes the secondary flux to die down rapidly, thus causing the a-c. component of fundamental frequency in the

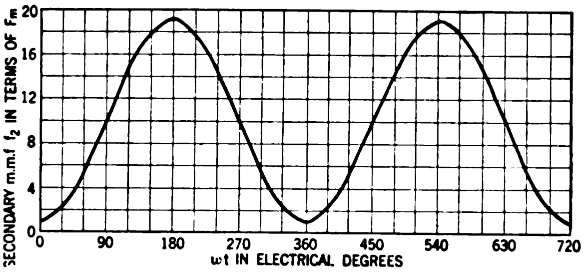


FIG. 9—CALCULATED CURVE OF SECONDARY M. M. F. AT SUDDEN SHORT CIRCUIT OF A POLYPHASE INDUCTION MOTOR HAVING THE SECONDARY EXCITED WITH DIRECT CURRENT

$$f_2 = F_m\left[\frac{\frac{P_1 P_2}{P_m^2} - \cos\omega t}{\frac{P_1 P_2}{P_m^2} - 1}\right]$$

Assumed Contents

$$\frac{P_m}{P_1} = \frac{P_m}{P_2} = 0.95$$

primary to die down faster than the second harmonic in the primary.

Case III. Single-phase short circuit on a polyphase induction machine under the assumption that the third line is opened at the instant the other two are

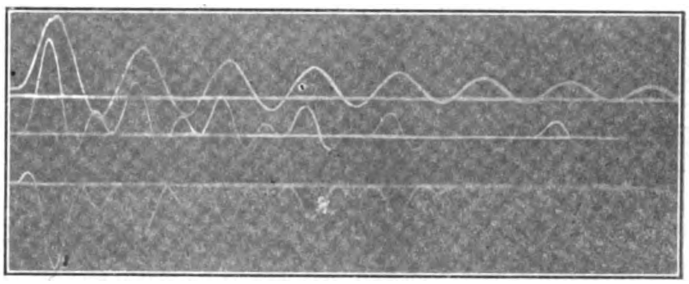


FIG. 10—OSCILLOGRAM OF THE SHORT-CIRCUIT CURRENT OF AN INDUCTION MOTOR WITH ONE PHASE OF ITS SECONDARY EXCITED WITH DIRECT CURRENT

50-h. p., three-phase, 60-cycle, 900-rev. per min., 550-volt—Three-phase short circuit at 550 volts, no load.
Secondary excited with direct current.
Upper curve—d-c. current in rotor.
Middle curve—primary current.
Lower curve—primary current.

short-circuited. The equation for the primary m. m. f. is,

$$f_1 = F_m \frac{\frac{P_1 P_2}{P_m^2}\cos\delta - \cos\omega t}{\frac{P_1 P_2}{P_m^2} - 1} \qquad (36)$$

and for the secondary m. m. f. is,

$$f_2 = F_m \frac{P_m}{P_2} \left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1} \left\{ \frac{P_1 P_2}{P_m^2} \cos\delta \cos\omega t - 1/2\,(1 + \cos 2\,\omega t) \right\} \right] \quad (39)$$

It will be noted that the curves from these equations with $\cos\delta = 1$, would be identical with those of Case II except that in this case f_1 corresponds to f_2 of the other, and *vice versa*. No test was made under these conditions.

Case IV. Single-phase short circuit on an induction machine with direct current in one phase of the secondary and the other phases open, that is,

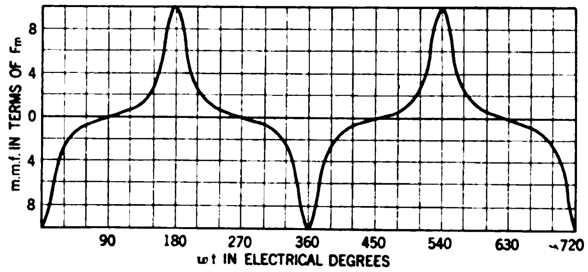


Fig. 11—Calculated Curve of Primary m. m. f. at Sudden Short Circuit of a Polyphase Induction Motor When Operating Single-Phase

$$\text{Primary m. m. f.} = f_1 = -F_m \frac{P_2}{P_m} \left[\frac{\cos\omega t}{\frac{P_1 P_2}{P_m^2} - \frac{1}{2}(1 + \cos 2\,\omega t)} \right]$$

Assumed Constants

$$\frac{P_m}{P_1} = \frac{P_m}{P_2} = 0.95$$

operating as a single-phase synchronous machine. The equation for the primary m. m. f. is,

$$f_1 = -F_m \frac{P_2}{P_m} \; \frac{\cos\omega t}{\frac{P_1 P_2}{P_m^2} - 1/2\,(1 + \cos 2\,\omega t)} \quad (44)$$

and for the secondary m. m. f. is,

$${}_2 = F_m \frac{P_1 P_2}{P_m^2} \; \frac{1}{\frac{P_1 P_2}{P_m^2} - 1/2\,(1 + \cos 2\,\omega t)} \quad (45)$$

Fig. 11 is the curve for f_1 plotted from equation (44). A test was not made under these conditions.

Tests

The tests in connection with this investigation were made on a 150-h. p., three-phase, induction motor. The short circuits were made with the machine operating at normal voltage, no load, and normal voltage, full load. Fig. 12 shows the diagram of connections indicating the position of the oscillograph shunts and the short-circuiting switch. About 50 oscillograms were taken. Typical results are given in Table I.

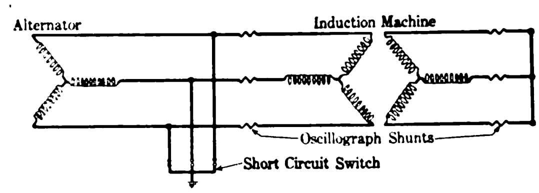


Fig. 12—Diagram of Connections for Short-Circuit Tests

It is important in appraising results of short-circuit tests to note the method by which the "short-circuit current" is determined from the oscillogram. The method used in these tests is illustrated by Fig. 1. The curves joining the crests (both positive and negative) of the wave are projected backward to the axis of zero time. The same exponential is used to extend the curve back from the first crest to the axis of zero time as was found to apply to the curve between the first two crests. The intercept at the axis of zero time is taken as twice the maximum value of the a-c. component.

TABLE I

Results from Analyzed Oscillograms
Short-Circuit Tests on 150-H. P., 720-Rev. per Min., 440-Volt, Three-Phase Induction Motor

Nature of Lad	Test No.	Initial Current*		Per cent† Reactance
		Primary	Secondary	
No load	36	1340	1180	13.8
	45	1420		13.0
	46	1170		15.8
	47‡	1560	1175	11.9
	48	1270		14.6
	49	1380	1150	13.4
	54	1380	1080	13.4
	55	1660	1180	11.1
	56	1390	865	13.3
	58	1190		15.5
	61	1290	916	14.3
Full load				
	50	1560		11.8
	51	1525	635	12.1
	52‡	1360	890	13.6
	53	1510	893	12.2

*Intial Current = r. m. s. of the a-c. component of initial short-circuit current.

†Per cent reactance $= 100 \times \dfrac{\text{normal current}}{\text{initial current (primary)}}$

‡Oscillogram shown in Fig. 7.

In the more general aspects these tests confirm the theory outlined in the foregoing. The particulars in which the tests do not agree, but which for the most part can be explained, are:

1. The attenuation factor r/L is higher than measured by the ohmic resistance and the inductance from the impedance test. That is, the current dies down in about 75 per cent of the calculated time. The calculated curve, Fig. 6, shows that six cycles are required for the current to die out, while the test curve, Fig. 7, shows that the current died out in four and one-half cycles.

This discrepancy can be explained by the facts that on account of eddy losses, etc., the effective resistance is greater than the measured ohmic resistance, and that on account of saturated leakage paths, the inductance is lower than that indicated by impedance test taken at near half voltage: both of these would shorten the transient.

2. The secondary m. m. f. at short circuit is apparently 60 to 75 per cent of the primary m. m. f. For this there seems to be no adequate explanation. This result, although roughly indicated by the tests, should, for reasons already given, be accepted with reserve.

3. The leakage reactance from results of these tests is about 25 per cent lower than that calculated from ordinary impedance tests (*i. e.* calculated reactance = 17 per cent, reactance from short-circuit tests = 13 per cent). This is explained by the fact that under short-circuit conditions the leakage paths are highly saturated, hence more current is required to maintain the flux. The amount by which the leakage reactance is reduced depends upon the extent to which the flux has died down at the end of the first half cycle after short circuit (at which time the greatest flux exists in the leakage paths). It therefore depends upon the time constant X/r.

In such a machine as the present 150-h. p. motor, in which X/r is about 6, the flux dies down to about 60 per cent of its initial value in the first half cycle, and completely disappears, as shown in Fig. 7, in four or five cycles. On the other hand, in a machine with $X/r = 20$, the flux would die down to only 85 per cent of its initial value in one-half cycle. This would mean not only more current on account of saturated leakage paths, but also an additional increase because it is now necessary to maintain 42 per cent more flux in those paths (*i. e.* $85/60 = 1.42$). Hence in large machines of relatively low resistance the total leakage reactance under conditions of short circuit would be less than the reactance from impedance test by a difference greater than the 25 per cent noted in this test. On the contrary the difference would be *less*, if X/r were smaller.

CONCLUSIONS

1. The sudden short-circuit current of a polyphase induction motor or generator, like that of a synchronous machine, is initially many times the normal rated current, and consists of an a-c. and a d-c. component, of approximately equal magnitudes in both primary and secondary.

2. The initial value of the r. m. s. of the a-c. component is equal to the impressed voltage divided by the total leakage reactance.

3. It follows that, assuming the same leakage inductance, the initial current will be the same whether the machine is short-circuited as an induction machine, or as a synchronous machine with the secondary excited with direct current.

4. The leakage reactance under short-circuit conditions is lower than indicated by ordinary impedance tests. As pointed out in paragraph (3) under TESTS, this is an important point to be considered in the design of certain large induction generators in which relatively low values of resistance may exist.

5. The actual duration of the transient is less than that indicated by the ohmic resistance and the reactance from impedance test, both because eddy currents increase the effective resistance, and saturation of leakage paths decrease L. Hence, r/L is increased.

6. Adding resistance to the primary winding will cause the d-c. component of that winding, and therefore the a-c. component of the secondary, to die out rapidly, and it will prolong the transient of the primary a-c. component and secondary d-c. component.

7. The effect of load upon the value of the short-circuit current is practically negligible.

The authors wish to acknowledge the assistance of Messrs. H. Maxwell, A. E. Averett, C. M. Davis and E. J. Burnham in making this investigation.

APPENDIX

ASSUMED CONDITIONS

The following assumptions are made in the development of the equations of short-circuit current: (1) Sine wave, m. m. f., (2) Zero shaft load, and (3) Zero resistance.

The first assumption is true in polyphase machines so far as the practical calculation of short-circuit currents is concerned. There are, of course, harmonics which exert appreciable influence in other problems of design, but little evidence of them is seen in oscillograms of short-circuit current.

Regarding the second assumption it has been pointed out in the preceding theory that the effect of load upon the initial value of short-circuit current is negligible.

The third assumption (zero resistance) does not appreciably affect the initial value of the short-circuit current in the ordinary machine, since the resistance is usually less than 3 or 4 per cent of the impedance. It does, however, affect the duration of the short-circuit current. Therefore, by neglecting r in the impedance and multiplying the resulting expression for current by $\epsilon^{-\frac{r}{L_o}t}$ the effect of resistance is, for practical purposes, taken into account.

Method of Attack

At the instant of short circuit the primary (stator) flux ceases to rotate since it must remain linked with the particular turns with which it was linked at the time the short circuit occurred. For the same reason, the secondary flux must continue to rotate. In a polyphase winding these fluxes are, at all times, supported by a resultant m. m. f. made up of ampere turns in each of the phases of the winding.

The problem at hand is to determine how the resultant m. m. f. in either member must adjust itself during rotation to maintain the constant value of flux. There are two sets of poles of practically the same magnitude, one stationary, the other rotating. The center lines of these poles afford references at which flux summations may be made involving equations including instantaneous values of m. m. f. For example, in Case I, where a polyphase short circuit is considered on a machine with a polyphase rotor, it is possible to sum up the following known values of fluxes in terms of known permeances and unknown instantaneous m. m. fs.

1. The total flux of the primary. The center line of this flux is, of course, the center line of the primary pole.
2. The primary flux in line with the secondary pole.
3. The total flux of the secondary.
4. The secondary flux in line with the primary pole.

In the case of a single-phase winding, since the current in all turns is in time phase, the direction of the resultant m. m. f., unlike the polyphase case, must be fixed by the position of the winding. Thus if both primary and secondary are single-phase only two equations are required. If one member is single-phase and the other polyphase three equations are required. In any case the reference lines are the same.

Notation

Φ_1 = flux linked with primary at instant of short circuit (stationary after short circuit).

Φ_2 = flux linked with secondary at instant of short circuit (rotating after short circuit).

F_m = magnetizing m. m. f. corresponding to the magnetizing current I_m in normal operation.

P_1 = permeance of primary = total primary flux per effective primary ampere turn (neglecting the effect of secondary).

P_2 = permeance of secondary = total secondary flux per effective secondary ampere turn (neglecting the effect of the primary).

P_m = permeance of mutual path = mutual flux per effective ampere turn of either primary or secondary.

ωt = electrical angle = $2 \pi f t$

f = electrical frequency

f_1 = total primary m. m. f. (at any time t) linking the primary flux and in line with the primary pole.

f_2 = total secondary m. m. f. (at any time t) linking the secondary flux and in line with the secondary pole.

f'_1 = the component of f_1 that is in line with f_2.

f'_2 = the component of f_2 that is in line with f_1.

I_m = magnetizing current at normal voltage.

I_n = normal rated current.

E = normal voltage per phase (*i. e.* per leg).

r_1 = resistance per phase of primary.

r_2 = resistance per phase of secondary reduced to primary terms.

r = resistance per phase = $r_1 + r_2$.

X = total leakage reactance per phase in primary terms.

X_p = per cent total reactance = $X I_n$ divided by the normal voltage per phase (expressed as a fraction $0.1 = 10$ per cent.)

L_0 = $X \div 2 \pi f$ = coefficient of total leakage induction.

i_1 = instantaneous primary current.

i_2 = instantaneous secondary current.

I_{01} = r. m. s. of initial value of a-c. component of primary short-circuit current.

I_{02} = r. m. s. of initial value of a-c. component of secondary short-circuit current.

Case 1. Polyphase Short Circuit

Polyphase primary, polyphase secondary.

At the instant of a no-load polyphase short circuit the total flux of the primary is,

$$\Phi_1 = F_m P_1 \tag{1}$$

and the total flux of the secondary is,

$$\Phi_2 = F_m P_m \tag{2}$$

Assuming zero resistance, Φ_1 and Φ_2 must remain constant and linked with the particular turns with which they were linked at the instant of short circuit.

At any time t after the short circuit, the rotor will have turned through the angle ωt. Then the primary flux in line with the rotor pole is,

$$\Phi_1 \cos \omega t = F_m P_1 \cos \omega t \tag{3}$$

and the secondary flux in line with the stator pole is,

$$\Phi_2 \cos \omega t = F_m P_m \cos \omega t \tag{4}$$

The equation for the total flux of the primary is,

$$f_1 P_1 + f^1{}_2 \, P_m = F_m P_1 \tag{5}$$

and for the secondary flux in line with the stator pole is,

$$f^1{}_2 P_2 + f_1 P_m = F_m P_m \cos \omega t \tag{6}$$

The equation for the total flux of the secondary is,

$$f_2 P_2 + f_1' P_m = F_m P_m \tag{7}$$

and for the primary flux in line with the rotor pole is,

$$f_1' P_1 + f_2 P_m = F_m P_1 \cos \omega t \quad (8)$$

Solving equations (5) and (6) for f_1 gives

$$f_1 = \frac{F_m}{\frac{P_1 P_2}{P_m^2} - 1} \left[\frac{P_1 P_2}{P_m^2} - \cos \omega t \right] \quad (9)$$

and solving (7) and (8) for f_2 gives

$$f_2 = F_m \frac{P_1}{P_m} \left[\frac{1 - \cos \omega t}{\frac{P_1 P_2}{P_m^2} - 1} \right] \quad (10)$$

The direct component of f_1 is,

$$f_{1d\text{-}c.} = \frac{F_m}{1 - \frac{P_m^2}{P_1 P_2}} \quad (11)$$

the a-c. component is,

$$f_{1a\text{-}c.} = - \frac{F_m}{\frac{P_1 P_2}{P_m^2} - 1} \cos \omega t \quad (12)$$

The direct component of f_2 is,

$$f_{2d\text{-}c.} = \frac{\frac{P_1}{P_m} F_m}{\frac{P_1 P_2}{P_m^2} - 1} \quad (13)$$

the a-c. component is,

$$f_{2a\text{-}c.} = - \frac{\frac{P_1}{P_m} F_m \cos \omega t}{\frac{P_1 P_2}{P_m^2} - 1} \quad (14)$$

Both f_1 and f_2 are a maximum at $\omega t = \pi$. At this instant f_1 is

$$f_1 \max = F_m \frac{\frac{P_1 P_2}{P_m^2} + 1}{\frac{P_1 P_2}{P_m^2} - 1} \quad (15)$$

and f_2 is

$$f_2 \max = F_m \frac{P_1}{P_m} \left[\frac{2}{\frac{P_1 P_2}{P_m^2} - 1} \right] \quad (16)$$

Thus, if $P_1 = P_2 = P$, and $P_m + P$ is greater than 0.9, the maximum values of f_1 and f_2 are equal within one-half of one per cent. Fig. 5 shows calculated curves for f_1 and f_2.

Before Case II is considered, equations (9) and (10) which give the m. m. f. of the primary and secondary for this case, will be expressed in terms of current instead of m. m. f. These equations involve the permeances P_1, P_2, and P_m, and the magnetizing m. m. f., F_m, which are related to the total per cent reactance X_p and normal current I_n as follows:

Let $P_1 - P_m$ = leakage flux of the primary per ampere turn,

and $P_2 - P_m$ = leakage flux of the secondary per secondary ampere turn.

Per cent reactance of primary

$$= \frac{\text{(leakage flux of primary at normal current)}}{\text{normal flux}}$$

but $F_m P_1$ = normal flux

and $F_n (P_1 - P_m)$ = leakage flux of primary at normal current.

Therefore, the per cent reactance of the primary is

$$\frac{F_n (P_1 - P_m)}{F_m P_1}$$

And since $\frac{F_n}{F_m} = \frac{I_n}{I_m}$

the per cent reactance of the primary is

$$\frac{I_n (P_1 - P_m)}{I_m P_1}$$

Assuming $P_1 = P_2 = P$, and that the primary and secondary ampere turns are equal, then the total reactance corresponding to normal current will be two times the primary reactance.

$$\text{Therefore, } X_p = \frac{2 I_n (P - P_m)}{I_m P} \quad (17)$$

The initial value of the short-circuit current is equal to normal rated current divided by the per cent total reactance.

$$\text{Therefore, } I_0 = \frac{I_n}{X_p}$$

And substituting the value of X_p from (17)

$$I_0 = \frac{I_m}{2\left(1 - \frac{P_m}{P}\right)} \quad (18)$$

$$\text{Since } \frac{F_m}{f_{1a\text{-}c.}} = \frac{\sqrt{2} I_m}{i_{1a\text{-}c.}}$$

Equation (12) may be rewritten in terms of current as follows:

$$i_{1a\text{-}c.} = \frac{\sqrt{2} I_m}{\frac{P_1 P_2}{P_m^2} - 1} \cos \omega t \quad (19)$$

In the ordinary machine P_m/P_1 is about 0.95, so I_0 may be substituted in (19) for

$$\frac{I_m}{\frac{P_1 P_2}{P_m^2} - 1}$$

without a significant error because the difference between I_0 from this expression (assuming $P_1 = P_2$) and I_0 from equation (18) is only 2 1/2 per cent. Likewise all the m. m. f. equations may be rewritten in terms of current as follows: from (11)

$$i_{1d\text{-}c.} = \sqrt{2}\, I_{01} \tag{20}$$

and from (12)

$$i_{1a\text{-}c.} = -\sqrt{2}\, I_{01} \cos \omega t \tag{21}$$

The total short-circuit current in the primary is the sum of the two components. That is,

$$i_1 = i_{1d\text{-}c.} + i_{1a\text{-}c.} = \sqrt{2}\, I_{01}\,(1 - \cos \omega\, t) \tag{22}$$

Also from (13)

$$i_{2d\text{-}c.} = \sqrt{2}\, I_{02} \tag{23}$$

And from (14)

$$i_{2a\text{-}c.} = -\sqrt{2}\, I_{02} \cos \omega\, t \tag{24}$$

And the total short-circuit current in the secondary is the sum of the two components.

$$i_1 = i_{2d\text{-}c.} + i_{2a\text{-}c.} = \sqrt{2}\, I_{02}\,(1 - \cos \omega\, t) \tag{25}$$

These equations were developed on the assumption of zero resistance. Multiplying (22) by

$$\epsilon^{-\frac{r_1}{L_0} t}$$

and (25) by

$$\epsilon^{-\frac{r_2}{L_0} t}$$

takes into account the effect of resistance. The final equations then become:

$$i_1 = \sqrt{2}\, I_{01}\, \epsilon^{-\frac{r_1}{L_0} t}\,(1 - \cos \omega\, t) \tag{26}$$

and $$i_2 = \sqrt{2}\, I_{02}\, \epsilon^{-\frac{r_2}{L_0} t}\,(1 - \cos \omega\, t) \tag{27}$$

Case II. Polyphase Short Circuit

Polyphase primary, one phase of secondary excited with direct current.

This case requires only three equations for the solution since the secondary is single-phase. The equations summing up the flux in the machine are as follows:

1. Total flux of the primary,
$$f_1 P_1 + f_2 P_m \cos \omega\, t = F_m P_m \tag{28}$$
2. Total flux of the secondary,
$$f_2 P_2 + f_1' P_m = F_m P_2 \tag{29}$$
3. Primary flux in line with the rotor pole,
$$f_1' P_1 + f_2 P_m = F_m P_m \cos \omega\, t \tag{30}$$

Solving equations (29) and (30) for f_2 gives

$$f_2 = F_m \frac{\frac{P_1 P_2}{P_m^2} - \cos \omega\, t}{\frac{P_1 P_2}{P_m^2} - 1} \tag{31}$$

Solving equations (28) and (31) for f_1 gives

$$f_1 = F_m \frac{P_m}{P_1}\left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1}\left\{\frac{P_1 P_2}{P_m^2} \cos \omega\, t - 1/2\,(1 + \cos 2\, \omega\, t)\right\}\right] \tag{32}$$

Case III. Single-Phase Short Circuit

Polyphase induction motor or generator. It is assumed that the third line is opened at the instant the other two are short-circuited.

Let δ = angle between center line of flux and center line of short-circuited phases at the instant of short circuit.

The flux caught in the short-circuited phases is,

$$\Phi_1 \cos \delta = F_m P_1 \cos \delta$$

The flux in the rotor is,

$$\Phi_2 = F_m P_m$$

Summing up the flux as in the previous cases gives the equations necessary for the solution.

The total flux of the primary is,

$$f_1 P_1 + f_2' P_m = F_m P_1 \cos \delta \tag{33}$$

The total flux of the secondary is

$$f_1 P_m \cos \omega\, t + f_2 P_2 = F_m P_m \tag{34}$$

The secondary flux in line with the stator pole is

$$f_1 P_m + f_2' P_2 = F_m P_m \cos \omega\, t \tag{35}$$

Solving (33) and (35) for f_1 gives

$$f_1 = F_m \frac{\frac{P_1 P_2}{P_m^2} \cos \delta - \cos \omega\, t}{\frac{P_1 P_2}{P_m^2} - 1} \tag{36}$$

and solving (36) and (34) for f_2 gives

$$f_2 = F_m \frac{P_m}{P_2}\left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1}\left\{\frac{P_1 P_2}{P_m^2} \cos \delta \cos \omega\, t - 1/2\,(1 + \cos 2\, \omega\, t)\right\}\right] \tag{37}$$

If the short circuit occurs at δ = 90 deg., that is, at maximum voltage, (36) becomes

$$f_1 = -F_m \frac{\cos \omega\, t}{\frac{P_1 P_2}{P_m^2} - 1} \tag{38}$$

and (37) becomes

$$f_2 = F_m \frac{P_m}{P_2}\left[1 - \frac{1}{\frac{P_1 P_2}{P_m^2} - 1}\right.$$

$$\left\{ - 1/2 \, (1 + \cos 2 \, \omega \, t) \right\} \Bigg] \qquad (39)$$

CASE IV. SINGLE-PHASE SHORT CIRCUIT

Single-Phase Stator, Single-Phase Rotor.

Let δ = angle between center line of stator pole and center line of rotor pole at the instant of short circuit.

The total flux of primary at the instant of short circuit is

$$\Phi_1 = F_m \, P_m \cos \delta$$

and the flux of secondary

$$\Phi_2 = F_m \, P_2$$

At any time after short circuit the primary flux is

$$f_1 \, P_1 + f_2 \, P_m \cos \omega t = F_m \, P_m \cos \delta \qquad (40)$$

and the secondary flux is

$$f_1 \, P_m \cos \omega \, t + f_2 \, P_2 = F_m \, P_2 \qquad (41)$$

Solving these equations for f_1 gives

$$f_1 = F_m \frac{P_2}{P_m} \; \frac{\cos \delta - \cos \omega \, t}{\dfrac{P_1 \, P_2}{P_m^2} - 1/2 \, (1 + \cos 2 \, \omega \, t)} \qquad (42)$$

Solving for f_2 gives

$$f_2 = F_m \frac{\dfrac{P_1 \, P_2}{P_m^2} - \cos \delta \cos \omega \, t}{\dfrac{P_1 \, P_2}{P_m^2} - 1/2 \, (1 + \cos 2 \, \omega \, t)} \qquad (43)$$

If the short circuit occurs at δ = 90 deg., that is maximum voltage, the equations become

$$f_1 = - F_m \frac{P_2}{P_m} \; \frac{\cos \omega \, t}{\dfrac{P_1 \, P_2}{P_m^2} - 1/2 \, (1 + \cos 2 \, \omega \, t)} \qquad (44)$$

and

$$f_2 = F_m \frac{1}{1 - 1/2 \, \dfrac{P_m^2}{P_1 \, P_2} \, (1 + \cos 2 \, \omega \, t)} \qquad (45)$$

INDUCTION MOTOR DATA

150-h. p., three-phase, 60 cycle, 720-rev. per min., ...	440-volt.
Normal current 185.. amperes..........	
Resistance per phase of primary........	0.027 ohms—2.1 per cent
Resistance per phase of secondary	0.029 ohms
Voltage Ratio:	
Primary volts per.. phase...........	254
Secondary volts per phase............	250
Excitation, 58 amperes at..................	440 volts
Impedance, 175 amperes at...................	71 volts
Total reactance in primary terms,...........	0.227 ohms, or 17 per cent

FROM THE ANNUAL REPORT OF THE BUREAU OF STANDARDS

The year has seen the Bureau of Standards of the Department of Commerce, organization change from a war-time to a peace basis. Although the armistice began during the period covered by the previous annual report, many investigations inaugurated during the war naturally held over for several months.

During the past year the Bureau's cooperation with the industries has been particularly close. The inauguration of new lines of work which was given a great impetus during the war has affected nearly every American industry, and the Bureau has been able to be of considerable assistance to these manufacturers through the accurate scientific data which it is able to furnish as a result of its researches.

The testing work carried out during the year has in some cases been slightly less than during the war period but in general the volume of this work has not decreased to any extent, owing to the fact that while the amount of work for the military departments has been somewhat less, that for the industries has been very much greater. The total number of tests conducted during the year for the Government was 72,398, and the tests conducted for the public numbered 34,501 or a total number of all tests of 106,899.

During the year the Bureau's staff comprised 381 statutory employees and 600 engaged in research and investigations specially authorized by Congress. The turn-over in personnel during the year was quite large, and this is a problem still demanding solution. For accurate, scientific work, such as that conducted by the Bureau, it is essential that stability in the personnel be maintained, and the salaries paid to employees should be commensurate with those obtained in the industries or educational institutions.

The annual conference on weights and measures was held at the Bureau from May 24-27, and a number of important questions were discussed. The greatest interest was displayed in the papers presented and in the discussions and debates. Among the subjects of special interest were sales by net weight, standardization of various commodities in package form and proposed legislation in reference to installation of testing gasoline measuring pumps.

The work in connection with electrolysis and gas engineering has been actively prosecuted and has resulted in very large savings to numerous municipalities.

Maximum Allowable Working Voltages in Cables

BY CHARLES W. DAVIS and DONALD M. SIMONS

of the Standard Underground Cable Company.

In recent years there has been a marked tendency, temporarily interrupted by the war, to operate electric power cable at increasingly higher voltages. For these higher voltage cables, the electric stress, or voltage per unit thickness of insulation is much higher than for the lower voltage cables, because the limiting overall dimensions have necessitated a *reduction in the factor of safety,* partly compensated for by improvement in the qualities of the insulating materials. When cables of still higher voltages are manufactured, the voltage stresses in the insulation will undoubtedly be proportionally higher again.

It has long been believed that a controlling factor in cable design is the maximum stress occurring at the working voltage, and were it possible to make cable with a dielectric that is under all conditions absolutely homogeneous throughout and in perfect contact with the conductors and the sheath, it seems not unreasonable to believe that maximum stress might prove the most important factor in design. Even the slight lack of uniformity, particularly in three-core cables, of the types that are most in use today, tends to produce incipient failure at points of less stress due in some cases to unevenly distributed compound, or in others to the uneven distribution of ionizable voids. Thus, as pointed out by the writers elsewhere[1], it may actually prove to be the case that in commercial cables of today, the average stress or the stress in and near the filler spaces in triplex cables is of more importance than maximum stress. Nevertheless the maximum stress is one of the limiting criteria and its obvious importance as greater uniformity of insulation is obtainable, is sufficient excuse for further study of it.

It is believed that it will be of interest and value to determine the limits of cable design as influenced by this one factor. Even if the final solution of the problem should be based upon a compromise of many conflicting factors, it is undoubtedly a step forward to investigate thoroughly the effect of any one limiting feature.

It would be interesting to know in advance what the highest operating voltages of the future will be, for a given limiting outside diameter, on the assumption that a certain value of maximum voltage stress in the insulation is the limiting feature in cable design. If we assume any limiting value of maximum stress, and assume that cables in the future will not be made with larger outside diameters than at present seem practiable, it will be possible to calculate the limiting working voltages that may be applied, if we know how to calculate the stresses in triplex cables operating under three-phase voltage, and if we know what size of conductor will produce the minimum value of maximum stress at the surface of the conductor for a given core diameter (*i. e.* the diameter under the lead sheath). In this article we propose to discuss methods of calculating stresses in triplex cables, giving examples of the calculation by the method given by R. W. Atkinson[2], and then to obtain a solution for the size of conductor which will produce a minimum value of maximum stress for a given core diameter. These data having been obtained, it will be easy to determine the maximum possible operating voltages for given limits of stress and outside diameter. It will be shown later, for instance, that, for a cable of equal belt and conductor insulation thicknesses and three-inch core diameter, 25,600 volts is the maximum allowable working voltage, if it should be decided that 25 kv. per cm. is the highest permissible stress.

Calculation of Electrostatic Stress

The maximum stress in a single-conductor cable (occurring at the conductor surface) can be found by the usual formula

$$G = \frac{E}{r \times \log R/r}$$

where E equals the voltage between conductor and sheath, R equals the radius of the cable over its insulation, and r equals the radius of the conductor, the logarithm being the natural logarithm. This formula is rather awkward to handle when many cables being figured, due to the fact that it involves the use of logarithms. R. W. Atkinson[2] has given a curve for obtaining this stress without the use of logarithms. The curve is reproduced here in Curve A, Fig. 1, and its method of use is discussed in Appendix A hereto.

In the above mentioned article[2], information is given which satisfies the long felt need for a method of determining the stresses in three-conductor cables under three-phase voltage. Up to the time of publication of this article, no adequate and easily workable method of doing this was available to the public. The author, very considerably extending the work and refining the methods the present writers used in 1913 to determine the stress in three-conductor cables, has obtained an experimental solution of this problem and accurately checked his method on single-conductor cables by comparing the experimental values with the theoretical values, and also by measurement of stresses in actual three-conductor cables.

The results of these experiments show that for anything like usual values of belt and conductor

1. *Electric Journal,* July 1920, Davis & Simons, "Allowable Working Stresses in High-Voltage Electric Cables."

2. A. I. E. E. Proceedings. June 1919, R. W. Atkinson, "The Dieletric Field in Electric Power Cables."

insulation the maximum stress occurs at the surface of the conductor in a three-conductor cable, at the point nearest the center of the cable, *i. e.* at the point marked (a) in Fig. 2, and the value is very closely equal to the stress obtained from calculation on the assumption that it is equal to that in a single-conductor cable of the same size of conductor and with an insulation thickness equal to the distance between the con-

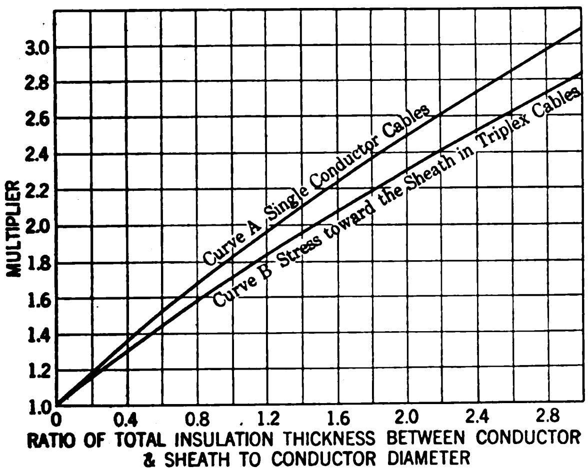


FIG. 1—ELECTROSTATIC STRESSES IN CABLES—RATIO OF MAXIMUM STRESS TO AVERAGE STRESS

(See "The Dielectric Field" by R. W. Atkinson, A. I. E. E. JOURNAL, June, 1919).

ductor surface and the center of the three-conductor cable. A small correction factor is involved dependent upon the relation between the conductor insulation and the conductor diameter. The value of this correction factor has been obtained experimentally for enough constructions of conductor size and insulation thickness to permit of the results being expressed in the form of an equation. Thus the calculation of maximum stress in a three-conductor cable resolves itself simply into the calculation of the stress in an equivalent single-conductor cable, with a final correction factor.

In applying this method it must be borne in mind that from the geometry of a three-conductor cable, the distance between the surface of a conductor and the center of the cable equals:

$$1.155\,t + 0.078\,d \qquad (1)$$

where t equals the conductor insulation thickness and d equals the conductor diameter. See Appendix B for an example.

As the correction factor is a small one, it is simpler to assume that it obeys a straight line law. The limiting values thus far obtained are as follows: For a ratio of conductor insulation thickness to conductor diameter equal to 0.288, the maximum stress in the equivalent single-conductor cable must be multiplied by 1.04 to obtain the actual maximum stress in the triplex cable considered; for a ratio of conductor insulation to conductor diameter equal to 0.625 the multiplier is 1.01. For values between these points, the multiplier can be found by interpolation, and when the ratio is greater than the larger one given the multiplier may be considered unity. We cannot safely go very far, however, in extrapolation below or above the ratios given, but this in most practical cases is obviously unimportant.

While the stress toward the center of the cable is the real maximum stress in all usual three-conductor cable formations, it is nevertheless a fact that, if the stress in the insulating material at the surface of the conductor is measured at all points around the entire circumference of the conductor, it will be discovered that the stress reaches a maximum value in two points, one being the point nearest the center or axis of the cable and the other that nearest the sheath of the cable. The former as above stated is the larger in all usual cases, although theoretically the stress toward the sheath might become larger if the thickness of the belt insulation were reduced far below the proportions necessary for mechanical strength.

It is often of interest to know what the stress is toward the sheath, both when the cable is operating under three-phase voltage and when it is being tested with single-phase voltage. This stress could be determined by Russell's formula for eccentric cylinders, if the stress at the surface of one conductor was not influenced by the presence of the other conductors. In point of fact it has been proved experimentally[2] not only that the presence of the other conductors has very little influence in cables of usual dimensions, but

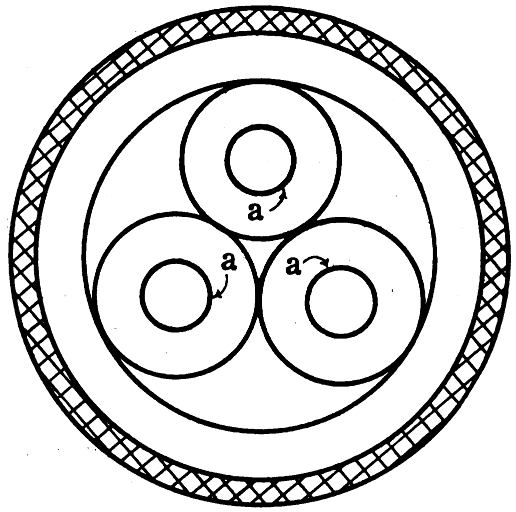


FIG. 2

(a) Shows location of maximum stress under three-phase voltage.

that the stress toward the sheath checks very closely with Russell's formula. The use of the formula is quite complicated, but the writer of the paper referred to has shown an easy solution giving results that are very closely identical with those given by Russell's formula. This is given in Curve B of Fig. 1. This curve is used in a manner similar to that used to find the stress in single-conductor cables, and an example is given in Appendix C.

The value of the stress at the surface of the conductor at the point nearest the sheath becomes of great importance in the case of an ungrounded neutral system in which one conductor has become grounded, the full line voltage being in that case impressed between each of the other two conductors and the lead sheath respectively. On account of the possibility of this occurrence, the belt insulation of cables used in a system with the neutral not grounded, is made considerably heavier than the belt of a cable in a grounded neutral system, usually being equal to the conductor insulation thickness. It must be borne in mind however, that in spite of the thicker belt of the cable in the ungrounded neutral system, the stress at the surface of the conductor toward the sheath in case one conductor should become grounded, is considerably higher than the stress toward the sheath in a grounded neutral system with the relatively thinner belt insulation. An example will make this clear. In a 00 triplex cable, insulated with 9/32 by 4/32 inches, at 25-kv. working pressure, the maximum stress, *i. e.* that toward the center of the cable, is 27.3 kv. per cm. and the stress toward the sheath is 23.5 kv. per cm., this cable being in operation in a grounded neutral system. In the case of an ungrounded neutral system, the make-up of the equivalent cable would undoubtedly be 00, insulated with 9/32 by 9/32 inches. Thus it would have 5/32 in. more belt insulation and therefore 5/32 in. more insulation between conductor and sheath. The maximum stress for this construction when the system is without grounds would be 27.5 kv. per cm. as before, and the stress toward the sheath would be 19.3 kv. per cm. If one conductor should be grounded, however, the full line voltage would be impressed between the other two conductors and the lead sheath, and the stress at the conductor surface toward the sheath would then become the real maximum stress and would be 33.3 kv. per cm. It is thus obvious that even with the heavy belt insulation ordinarily used in ungrounded neutral systems, the cable is under much more severe strain when one conductor becomes grounded, than is a cable with thinner belt insulation on a grounded neutral system.

All the stresses which have been calculated above, and also those which will be given later, are figured on the basis of smooth round conductors equal in diameter to the outside diameter of a strand of usual formation and of the size stated. The effect of the stranding on increasing the stress has therefore not been taken into consideration. The magnitude of the effect of the strands upon dielectric stress has been discussed by R. W. Atkinson[2] who gives four figures, showing that on the average the stress will be increased about 20 per cent from this cause. It remains for further experimentation to discover whether or not the greater stress of stranded cable as compared to solid conductors is of great importance, both when the cable is under continuous high stress and when it is subjected to momentary overvoltages. It would appear that in a homogeneous insulation, at least, there must be a considerable effect due to this additional stress.

Stress Tables

The calculations of the various stresses mentioned above are all more or less simple, but if it is desired to calculate the stresses in a large number of cables it becomes a rather laborious process. The stress Tables I, IA, II, III and IV have therefore been prepared.

TABLE I

MAXIMUM VOLTAGE STRESS IN TRIPLEX CABLES UNDER THREE-PHASE VOLTAGE

To obtain the maximum stress for a given cable, find the number in the following table corresponding to the size of conductor and conductor insulation thickness. Multiply the voltage in kv. between conductors by this number, and the product will be the maximum stress in kilovolts per centimeter.

Size A. W. G. strand	Diameter	Conductor insulation thickness in 32nd inches							
		3	4	5	6	7	8	9	10
	in.								
No. 4	0.232	2.74	2.28	1.97	1.77	1.63	1.51	1.42	1.35
3	0.260	2.63	2.18	1.89	1.68	1.54	1.42	1.35	1.27
2	0.292	2.52	2.10	1.82	1.62	1.47	1.36	1.28	1.21
1	0.328	2.42	2.01	1.74	1.55	1.40	1.29	1.21	1.14
0	0.373	2.30	1.92	1.66	1.48	1.34	1.23	1.14	1.08
00	0.418	2.21	1.85	1.60	1.42	1.29	1.18	1.09	1.03
000	0.470	2.11	1.77	1.53	1.36	1.23	1.13	1.05	0.98
0000	0.528	2.02	1.69	1.47	1.31	1.18	1.08	1.01	0.94
cir. mils.									
250,000	0.575	1.95	1.64	1.42	1.27	1.15	1.05	0.98	0.91
300,000	0.630		1.58	1.38	1.23	1.11	1.02	0.94	0.88
350,000	0.681		1.53	1.34	1.19	1.08	0.99	0.92	0.86
400,000	0.728			1.30	1.15	1.05	0.97	0.90	0.84
450,000	0.772			1.27	1.13	1.03	0.95	0.88	0.82
500,000	0.815			1.25	1.11	1.01	0.93	0.86	0.81
550,000	0.855			1.22	1.09	0.99	0.91	0.85	0.79
600,000	0.893				1.08	0.98	0.90	0.84	0.78
650,000	0.929				1.06	0.96	0.89	0.82	0.77
1,000,000	1.152				0.97	0.89	0.82	0.76	0.71

TABLE I (*Continued*)

Size A. W. G. strand	Diameter	Conductor insulation thickness in 32nd inches					
		11	12	13	14	15	16
	in.						
4	0.232	1.29	1.23	1.19	1.15	1.11	1.08
3	0.260	1.22	1.16	1.12	1.08	1.04	1.01
2	0.292	1.15	1.10	1.05	1.02	0.98	0.95
1	0.328	1.09	1.04	1.00	0.96	0.93	0.90
0	0.373	1.02	0.98	0.94	0.90	0.87	0.84
00	0.418	0.97	0.93	0.89	0.85	0.82	0.80
000	0.470	0.93	0.88	0.84	0.81	0.78	0.75
0000	0.528	0.89	0.84	0.80	0.77	0.74	0.71
cir. mils							
250,000	0.575	0.86	0.81	0.77	0.74	0.71	0.69
300,000	0.630	0.83	0.79	0.75	0.71	0.68	0.66
350,000	0.681	0.81	0.76	0.72	0.69	0.66	0.64
400,000	0.728	0.79	0.75	0.71	0.67	0.65	0.62
450,000	0.772	0.77	0.73	0.69	0.66	0.63	0.61
500,000	0.815	0.76	0.72	0.68	0.65	0.62	0.60
550,000	0.855	0.74	0.70	0.67	0.64	0.61	0.59
600,000	0.893	0.73	0.69	0.66	0.63	0.60	0.58
650,000	0.929	0.72	0.68	0.65	0.62	0.59	0.57
1,000,000	1.152	0.67	0.63	0.60	0.57	0.55	0.53

TABLE IA
MILLIMETER GAGE
MAXIMUM VOLTAGE STRESS FOR TRIPLEX CABLES UNDER THREE-PHASE VOLTAGE

This table is the same as Table I, except that it is for use in connection with cables whose dimensions are given in millimeters.

Conductor area in sq. mm.	Diameter in mm.	Total insulation between conductors in mm.							
		6	6.5	7	7.5	8	9	10	11
16	5.13	2.48	2.36	2.24	2.16	2.07	1.94	1.84	1.74
25	6.40	2.29	2.18	2.07	1.98	1.90	1.77	1.66	1.58
35	7.66	2.15	2.04	1.95	1.86	1.78	1.66	1.55	1.46
50	9.16	2.01	1.92	1.83	1.75	1.68	1.55	1.45	1.37
70	10.82	1.90	1.80	1.72	1.64	1.58	1.46	1.37	1.29
95	12.60	1.79	1.70	1.63	1.56	1.49	1.38	1.29	1.22
120	14.23	1.71	1.63	1.56	1.49	1.43	1.32	1.24	1.16
150	15.90	1.64	1.56	1.49	1.43	1.37	1.27	1.19	1.12
185	17.67		1.52	1.43	1.37	1.32	1.23	1.15	1.08
240	20.13			1.36	1.30	1.25	1.17	1.09	1.03
310	22.88				1.24	1.19	1.11	1.04	0.98

Conductor area in sq. mm.	Diameter in mm.	Total insulation between conductors in mm.					
		12	13	14	15	16	17
16	5.13	1.67	1.60	1.53	1.49	1.44	1.40
25	6.40	1.50	1.43	1.37	1.34	1.29	1.25
35	7.66	1.39	1.32	1.26	1.23	1.18	1.15
50	9.16	1.29	1.22	1.17	1.13	1.09	1.05
70	10.82	1.22	1.16	1.09	1.05	1.01	0 98
95	12.60	1.15	1.10	1.03	1.00	0.96	0.92
120	14.23	1.10	1.05	0.99	0.96	0.92	0.88
150	15.90	1.06	1.01	0.95	0.92	0.88	0.85
185	17.67	1.02	0.97	0.92	0.88	0.85	0.81
240	20.13	0.97	0.92	0.87	0.84	0.81	0.78
310	22.88	0.93	0.89	0.83	0.81	0.77	0.75

In all cases the stress may be found by finding a number in the table corresponding to the size of conductor and insulation thickness of the cable in question, and multiplying this number by the line voltage in kilovolts.

Calculation of the Size of Conductor Giving a Minimum Value of Maximum Stress for a Triplex Cable of Given Core Diameter

It is a well-known fact that in single-conductor cables, for a given core diameter, (*i. e.* diameter over insulation), and voltage, the minimum value of the stress at the surface of the conductor will exist when the ratio of R/r equals 2.718 or the base of the natural system of logarithms. Let us consider the many arrangements of conductor size and insulation thickness that may be possible with a given core diameter for a three-conductor cable, and the stresses which will result therefrom. If we use very thick insulation for a given core diameter, we will be forced to employ a small conductor, which will produce a relatively high stress due to the extreme curvature of the conductor. On the other hand, if we use a large conductor diameter, we will have room for only a thin insulation and this will again produce a high stress. Between these two limits there exists one arrangement of conductor diameter and insulation thickness which will produce the minimum stress for a given core diameter. Let us consider a cable of three-inch core diameter whose conductor insulation and belt insulation are equal in thickness, and calculate the values of maximum stress at 20 kv. pressure for various

TABLE II
MAXIMUM VOLTAGE STRESS TOWARD THE SHEATH IN TRIPLEX CABLES

To obtain the maximum stress toward the sheath for a given cable, find the number in the following tables corresponding to the size of conductor and the total insulation between conductor and sheath. Multiply this number by the voltage between conductors in kv., and the product will be this maximum stress in kilovolts per centimeter.

Note that there are two points of maximum stress at the conductor surface in a triplex cable under three-phase voltage. The larger is usually toward the center, and can be obtained from other tables.

If the maximum stress under single-phase voltage is desired, (*i. e.*, three conductors vs. sheath, two conductors vs. other conductor and sheath etc.), this table may be used by multiplying the product by the square root of 3 (1.73). In this condition, the maximum stress in usual commercial cables occurs at the conductor surface toward the sheath.

Size A. W. G. strand	Condr. diameter	Total insulation thickness, conductors to sheath, in 32nd. inches										
		8	9	10	11	12	13	14	15	16	17	18
No. 4	0.232 in.	1.59	1.48	1.39	1.32	1.25	1.20	1.16	1.12	1.08	1.05	1.02
3	0.260	1.53	1.42	1.33	1.26	1.19	1.14	1.10	1.05	1.02	0.99	0.96
2	0.292	1.46	1.36	1.27	1.20	1.14	1.08	1.04	1.00	0.97	0.93	0.91
1	0.328	1.41	1.30	1.22	1.15	1.09	1.03	0.99	0.95	0.92	0.89	0.86
0	0.373	1.35	1.25	1.16	1.09	1.04	0.98	0.94	0.90	0.87	0.84	0.81
00	0.418	1.31	1.21	1.12	1.05	0.99	0.94	0.90	0.86	0.83	0.80	0.77
000	0.470	1.27	1.17	1.08	1.01	0.96	0.91	0.86	0.83	0.78	0.76	0.74
0000	0.528	1.23	1.13	1.05	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.70
250,000 cir. mils	0.575	1.21	1.10	1.02	0.95	0.90	0.85	0.80	0.77	0.74	0.71	0.68
300,000	0.630	1.18	1.08	1.00	0.93	0.87	0.82	0.78	0.75	0.72	0.69	0.66
350,000	0.681	1.16	1.06	0.98	0.91	0.85	0.81	0.76	0.73	0.70	0.67	0.64
400,000	0.728	1.15	1.04	0.96	0.90	0.84	0.79	0.75	0.72	0.68	0.65	0.63
450,000	0.772	1.14	1.03	0.95	0.88	0.83	0.78	0.74	0.70	0.67	0.64	0.62
500,000	0.815	1.12	1.02	0.94	0.87	0.82	0.77	0.73	0.69	0.66	0.63	0.61
550,000	0.855	1.11	1.01	0.93	0.86	0.81	0.76	0.72	0.68	0.65	0.62	0.60
600,000	0.893	1.10	1.00	0.92	0.85	0.80	0.75	0.71	0.67	0.64	0.61	0.59
650,000	0.929	1.10	1.00	0.91	0.85	0.79	0.74	0.70	0.67	0.64	0.61	0.58
1,000,000	1.152	1.06	0.96	0.88	0.81	0.76	0.71	0.67	0.64	0.60	0.58	0.55

TABLE II—*Continued*

Size A. W. G. strand	Condr. diameter	Total insulation thickness, conductors to sheath, in 32nd inches									
		19	20	21	22	23	24	25	26	27	28
4	0.232 in.	0.99	0.97	0.95	0.93	0.91	0.90	0.88	0.87	0.85	0.84
3	0.260	0.93	0.91	0.89	0.87	0.86	0.84	0.83	0.81	0.80	0.78
2	0.292	0.88	0.86	0.84	0.82	0.80	0.79	0.77	0.76	0.75	0.73
1	0.328	0.83	0.81	0.79	0.78	0.76	0.74	0.73	0.71	0.70	0.69
0	0.373	0.78	0.77	0.75	0.73	0.71	0.70	0.68	0.67	0.65	0.64
00	0.418	0.75	0.73	0.71	0.69	0.68	0.66	0.64	0.63	0.62	0.61
000	0.470	0.71	0.69	0.67	0.66	0.64	0.62	0.61	0.60	0.59	0.58
0000	0.528	0.68	0.66	0.64	0.62	0.61	0.59	0.58	0.57	0.56	0.54
250,000 cir. mils	0.575	0.66	0.64	0.62	0.60	0.59	0.57	0.56	0.55	0.54	0.52
300,000	0.630	0.64	0.62	0.60	0.58	0.57	0.55	0.54	0.52	0.51	0.50
350,000	0.681	0.62	0.60	0.58	0.56	0.55	0.54	0.52	0.51	0.50	0.49
400,000	0.728	0.61	0.59	0.57	0.55	0.54	0.52	0.51	0.50	0.49	0.48
450,000	0.772	0.60	0.58	0.56	0.54	0.53	0.51	0.50	0.49	0.47	0.46
500,000	0.815	0.59	0.57	0.55	0.53	0.52	0.50	0.49	0.48	0.46	0.45
550,000	0.855	0.58	0.56	0.54	0.52	0.51	0.49	0.48	0.47	0.46	0.45
600,000	0.893	0.56	0.54	0.53	0.51	0.49	0.48	0.47	0.46	0.45	0.43
650,000	0.929	0.56	0.54	0.52	0.51	0.48	0.48	0.47	0.45	0.44	0.43
1,000,000	1.152	0.53	0.51	0.49	0.48	0.46	0.45	0.43	0.42	0.41	0.40

TABLE III

MAXIMUM STRESS TABLE FOR TYPE "H" CABLES

To obtain the maximum stress for a given cable, find the number in the following table corresponding to its size of conductor and its insulation thickness on each conductor. Multiply the voltage in kv. between conductors by this number, and the product will be the maximum stress in kilovolts per centimeter.

Size A. W. G. strand	Diameter	Conductor insulation thickness in 32nd inches																
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	in.																	
No. 4	0.232	2.67	2.30	2.04	1.85	1.70	1.59	1.50	1.42	1.36	1.30	1.25	1.21	1.17	1.14	1.11	1.08	1.05
3	0.260	2.59	2.21	1.95	1.77	1.62	1.52	1.43	1.35	1.29	1.23	1.18	1.14	1.11	1.08	1.06	1.02	0.99
2	0.292	2.52	2.14	1.88	1.70	1.55	1.45	1.36	1.28	1.22	1.17	1.12	1.08	1.05	1.02	0.99	0.96	0.94
1	0.328	2.44	2.07	1.82	1.62	1.48	1.39	1.30	1.23	1.16	1.11	1.06	1.02	0.99	0.96	0.94	0.91	0.88
0	0.373	2.37	2.00	1.76	1.57	1.43	1.32	1.24	1.17	1.10	1.05	1.01	0.97	0.94	0.91	0.88	0.85	0.84
00	0.418	2.31	1.95	1.70	1.52	1.38	1.28	1.19	1.12	1.06	1.00	0.96	0.92	0.89	0.86	0.83	0.81	0.79
000	0.470	2.27	1.90	1.65	1.47	1.33	1.23	1.14	1.07	1.01	0.96	0.91	0.88	0.85	0.82	0.79	0.77	0.74
0000	0.528	2.23	1.86	1.61	1.43	1.30	1.19	1.11	1.04	0.98	0.93	0.87	0.84	0.81	0.78	0.75	0.73	0.71
cir. mils																		
250,000	0.575	2.19	1.82	1.58	1.40	1.26	1.16	1.07	1.01	0.95	0.90	0.84	0.81	0.78	0.75	0.72	0.70	0.68
300,000	0.630	2.16	1.80	1.55	1.37	1.24	1.13	1.05	0.98	0.92	0.87	0.82	0.79	0.76	0.73	0.70	0.68	0.66
350,000	0.681	2.14	1.77	1.52	1.35	1.21	1.11	1.03	0.96	0.90	0.85	0.80	0.76	0.74	0.71	0.68	0.66	0.64
400,000	0.728	2.12	1.75	1.50	1.33	1.20	1.09	1.01	0.94	0.88	0.83	0.79	0.75	0.72	0.69	0.66	0.64	0.62
450,000	0.772	2.11	1.73	1.49	1.31	1.18	1.07	0.99	0.92	0.87	0.82	0.77	0.73	0.70	0.68	0.65	0.63	0.61
500,000	0.815	2.09	1.72	1.47	1.30	1.17	1.06	0.98	0.91	0.85	0.81	0.76	0.72	0.69	0.66	0.64	0.62	0.60
550,000	0.855	2.07	1.71	1.46	1.29	1.16	1.05	0.97	0.90	0.84	0.80	0.75	0.71	0.68	0.65	0.63	0.61	0.59
600,000	0.893	2.06	1.70	1.45	1.28	1.14	1.04	0.96	0.89	0.83	0.79	0.74	0.70	0.67	0.65	0.62	0.60	0.58
650,000	0.929	2.05	1.69	1.44	1.27	1.14	1.03	0.95	0.88	0.83	0.78	0.73	0.69	0.66	0.64	0.61	0.59	0.57
1,000,000	1.152	2.01	1.65	1.40	1.22	1.10	0.99	0.91	0.84	0.79	0.74	0.69	0.65	0.63	0.60	0.58	0.55	0.53

TABLE IV

TABLE OF MAXIMUM STRESS IN SINGLE-CONDUCTOR CABLES

To obtain the stress for a given cable, find the number in the following table corresponding to its size of conductor and insulation thickness. Multiply the voltage in kv. by this number and the product will be the maximum voltage stress in kilovolts per centimeter.

Size A. W. G. strand	Diameter	Conductor insulation thickness in 32nd inches										
		3	4	5	6	7	8	9	10	11	12	13
No. 4	0.232 in.	5.73	4.64	3.98	3.53	3.20	2.96	2.76	2.60	2.47	2.35	2.25
3	0.260	5.58	4.49	3.83	3.39	3.06	2.82	2.63	2.47	2.34	2.23	2.14
2	0.292	5.44	4.36	3.70	3.26	2.94	2.70	2.51	2.36	2.23	2.12	2.02
1	0.328	5.31	4.23	3.58	3.15	2.83	2.59	2.40	2.25	2.12	2.01	1.92
0	0.373	5.18	4.11	3.47	3.03	2.72	2.48	2.29	2.14	2.01	1.91	1.82
00	0.418	5.08	4.02	3.37	2.94	2.63	2.39	2.21	2.06	1.93	1.83	1.74
000	0.470	4.99	3.93	3.29	2.86	2.54	2.31	2.13	1.98	1.86	1.76	1.67
0000	0.528	4.92	3.85	3.21	2.78	2.47	2.24	2.06	1.91	1.79	1.69	1.60
250,000 cir. mils	0.575	4.87	3.80	3.16	2.73	2.42	2.19	2.01	1.86	1.74	1.64	1.55
300,000	0.630	4.80	3.74	3.10	2.68	2.37	2.14	1.96	1.82	1.69	1.59	1.51
350,000	0.681	4.75	3.70	3.06	2.64	2.33	2.10	1.92	1.78	1.66	1.56	1.47
400,000	0.728	4.73	3.66	3.03	2.60	2.30	2.07	1.89	1.75	1.63	1.53	1.45
450,000	0.772	4.70	3.64	3.01	2.57	2.27	2.04	1.86	1.72	1.60	1.50	1.42
500,000	0.815	4.67	3.62	2.98	2.55	2.25	2.02	1.84	1.70	1.58	1.48	1.40
550,000	0.855	4.65	3.60	2.96	2.53	2.23	2.00	1.82	1.68	1.56	1.46	1.38
600,000	0.893	4.63	3.58	2.94	2.52	2.21	1.98	1.81	1.66	1.54	1.45	1.36
650,000	0.929	4.62	3.56	2.92	2.50	2.20	1.97	1.79	1.65	1.53	1.43	1.35
700,000	0.964	4.60	3.55	2.91	2.49	2.19	1.96	1.78	1.64	1.52	1.42	1.34
750,000	0.998	4.58	3.53	2.90	2.47	2.17	1.95	1.77	1.62	1.51	1.41	1.33
800,000	1.031	4.57	3.52	2.89	2.46	2.16	1.93	1.75	1.61	1.49	1.40	1.31
850,000	1.062	4.56	3.51	2.88	2.45	2.15	1.92	1.75	1.60	1.49	1.39	1.30
900,000	1.093	4.56	3.50	2.87	2.44	2.14	1.91	1.74	1.59	1.48	1.38	1.29
950,000	1.123	4.55	3.49	2.86	2.44	2.13	1.90	1.73	1.58	1.47	1.37	1.29
1,000,000	1.152	4.54	3.48	2.85	2.43	2.13	1.89	1.72	1.58	1.46	1.37	1.28

TABLE IV—*Continued*

Size A. W. G. strand	Diameter	Conductor insulation thickness in 32nd inch																		
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
4	0.232 in.	2.17	2.09	2.03	1.97	1.92	1.87	1.83	1.79	1.75	1.72	1.69	1.66	1.63	1.60	1.58	1.56	1.53	1.51	1.50
3	0.260	2.05	1.98	1.92	1.86	1.81	1.76	1.72	1.68	1.65	1.61	1.58	1.55	1.53	1.50	1.48	1.46	1.43	1.42	1.40
2	0.292	1.94	1.88	1.81	1.75	1.71	1.67	1.62	1.58	1.55	1.51	1.48	1.46	1.43	1.41	1.38	1.36	1.34	1.32	1.31
1	0.328	1.85	1.78	1.72	1.66	1.61	1.57	1.53	1.49	1.45	1.43	1.40	1.37	1.35	1.32	1.30	1.28	1.26	1.24	1.22
0	0.373	1.75	1.68	1.62	1.57	1.52	1.47	1.44	1.39	1.37	1.34	1.31	1.28	1.26	1.23	1.21	1.19	1.17	1.16	1.14
00	0.418	1.67	1.59	1.54	1.49	1.44	1.40	1.36	1.33	1.29	1.26	1.24	1.21	1.19	1.16	1.14	1.13	1.11	1.09	1.07
000	0.470	1.58	1.53	1.47	1.42	1.37	1.33	1.29	1.26	1.22	1.20	1.17	1.14	1.12	1.10	1.08	1.06	1.04	1.03	1.01
0000	0.528	1.52	1.46	1.40	1.35	1.31	1.26	1.23	1.19	1.15	1.13	1.11	1.08	1.06	1.04	1.02	1.00	0.98	0.97	0.95
250,000 cir. mils	0.575	1.48	1.42	1.36	1.31	1.26	1.22	1.19	1.15	1.12	1.09	1.07	1.04	1.02	1.00	0.98	0.96	0.94	0.93	0.91
300,000	0.630	1.43	1.37	1.31	1.26	1.22	1.18	1.14	1.11	1.08	1.05	1.03	1.00	0.98	0.96	0.94	0.92	0.91	0.89	0.87
350,000	0.681	1.40	1.33	1.28	1.23	1.18	1.14	1.11	1.08	1.04	1.02	0.99	0.97	0.95	0.93	0.91	0.89	0.87	0.86	0.84
400,000	0.728	1.37	1.31	1.25	1.20	1.16	1.11	1.08	1.05	1.02	0.99	0.97	0.94	0.92	0.90	0.88	0.86	0.85	0.83	0.82
450,000	0.772	1.35	1.28	1.23	1.18	1.13	1.09	1.06	1.03	1.00	0.97	0.95	0.92	0.90	0.88	0.86	0.84	0.83	0.81	0.80
500,000	0.815	1.32	1.26	1.21	1.16	1.11	1.07	1.04	1.01	0.98	0.95	0.93	0.90	0.88	0.86	0.84	0.83	0.81	0.79	0.78
550,000	0.855	1.31	1.24	1.19	1.14	1.10	1.05	1.02	0.99	0.96	0.93	0.91	0.89	0.87	0.85	0.83	0.81	0.79	0.78	0.76
600,000	0.893	1.28	1.23	1.17	1.12	1.07	1.04	1.00	0.98	0.94	0.92	0.90	0.87	0.85	0.83	0.81	0.80	0.78	0.76	0.75
650,000	0.929	1.28	1.22	1.16	1.11	1.07	1.03	0.99	0.96	0.93	0.91	0.88	0.86	0.84	0.82	0.80	0.78	0.77	0.75	0.74
700,000	0.964	1.26	1.20	1.15	1.10	1.06	1.02	0.98	0.95	0.92	0.90	0.87	0.85	0.83	0.81	0.79	0.77	0.76	0.74	0.73
750,000	0.998	1.25	1.19	1.15	1.09	1.04	1.00	0.97	0.94	0.91	0.89	0.86	0.84	0.82	0.80	0.78	0.76	0.75	0.73	0.72
800,000	1.031	1.24	1.18	1.13	1.08	1.04	1.00	0.96	0.93	0.90	0.88	0.85	0.83	0.80	0.79	0.77	0.75	0.74	0.72	0.71
850,000	1.062	1.23	1.17	1.12	1.07	1.03	0.99	0.96	0.92	0.89	0.87	0.84	0.82	0.80	0.78	0.76	0.74	0.73	0.71	0.70
900,000	1.093	1.23	1.16	1.11	1.06	1.02	0.98	0.95	0.91	0.88	0.86	0.83	0.81	0.79	0.77	0.75	0.73	0.72	0.70	0.69
950,000	1.123	1.22	1.16	1.10	1.05	1.01	0.97	0.94	0.91	0.88	0.85	0.83	0.80	0.78	0.76	0.75	0.73	0.71	0.70	0.68
1,000,000	1.152	1.21	1.15	1.10	1.05	1.00	0.96	0.93	0.90	0.87	0.84	0.82	0.80	0.78	0.76	0.74	0.72	0.71	0.69	0.68
1,100,000	1.209	1.20	1.13	1.08	1.03	0.99	0.95	0.92	0.89	0.86	0.83	0.81	0.79	0.77	0.75	0.73	0.71	0.70	0.68	0.67
1,200,000	1.263	1.18	1.12	1.07	1.02	0.98	0.94	0.91	0.87	0.85	0.82	0.80	0.77	0.75	0.73	0.72	0.70	0.68	0.67	0.66
1,300,000	1.315	1.17	1.11	1.06	1.01	0.97	0.93	0.90	0.86	0.84	0.81	0.79	0.76	0.74	0.72	0.71	0.69	0.68	0.66	0.65
1,400,000	1.364	1.17	1.10	1.05	1.00	0.96	0.92	0.89	0.86	0.83	0.80	0.78	0.76	0.73	0.72	0.70	0.68	0.67	0.65	0.64
1,500,000	1.412	1.16	1.09	1.04	0.99	0.95	0.92	0.88	0 85	0.82	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.66	0.64	0.63
1,600,000	1.459	1.15	1.09	1.03	0.99	0.95	0.91	0.87	0.84	0.81	0.79	0.76	0.74	0.72	0.70	0.68	0.67	0.65	0.64	0.62
1,700,000	1.504	1.14	1.08	1.03	0.98	0.94	0.90	0.86	0.83	0.81	0.78	0.76	0.74	0.71	0.70	0.68	0.66	0.65	0.63	0.62

conductor diameters, the insulation thickness of course varying so as to keep the three-inch core diameter. The results are shown graphically in Fig. 3 in which it may be seen that the conductor diameter for the minimum value of maximum stress is approximately 0.51 in. This could be done for any core diameter, and the corresponding curve plotted.

Let us now however, consider the general case, and obtain a mathematical solution of the minimum value of maximum stress for a given core diameter. This

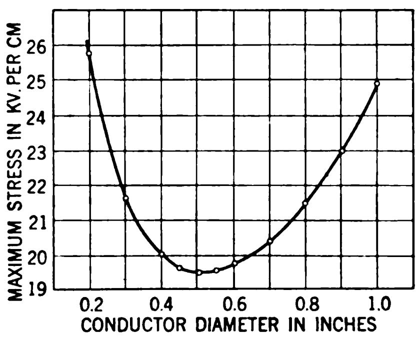


FIG. 3—CURVE SHOWING THE VARIATION OF MAXIMUM STRESS WITH SIZE OF CONDUCTOR FOR TRIPLEX CABLES OF A GIVEN CONSTANT CORE DIAMETER

This curve was calculated for a triplex cable of 3-in. core diameter at 20,000 volts pressure between conductors. The insulation to ground equals the insulation between conductors, and varies with the conductor diameter so as to keep the core diameter constant.

will vary according to what proportion of belt insulation is used. We will take first the case where the belt insulation equals the conductor insulation, in other words, where the insulation to ground equals the insulation between conductors, as would normally be used in ungrounded neutral systems. If a straight line curve is assumed for the final correction factor as suggested above, this factor may be expressed as equal to $\dfrac{1.066\,d - 0.089\,t}{d}$, using the two points given by Atkinson. The maximum stress at the conductor surface therefore may be expressed as follows:

$$G_{max} = \frac{E\left(\dfrac{1.066\,d - 0.089\,t}{d}\right)}{d/2\ .\ \log_e \Delta/d}$$

where G_{max} = the maximum stress at the conductor surface,

E = effective kilovolts between conductors and ground,

d = conductor diameter,

t = conductor insulation thickness = belt insulation thickness,

Δ = diameter over insulation of the "equivalent single-conductor cable."

Let D = diameter under lead sheath of triplex cable, *i. e.*, core diameter

and let

t' = insulation thickness of "equivalent single-conductor cable."

It is now desired to express G_{max} in terms of D and d

$t' = 1.155\,t + 0.078\,d$, from formula (1)

but $\Delta = 2\,t' + d$

$\therefore\ \Delta = 2.31\,t + 1.155\,d$

Now $D = 2.155\,(2\,t + d) + 2\,t = 6.31\,t + 2.155\,d$

(From the geometry of a triplex cable)

$\therefore\ \Delta = 0.3661\,D + 0.3661\,d$

$$\therefore\ G_{max} = \frac{2\,E\left(\dfrac{1.0964\,d - 0.01401\,D}{d}\right)}{d\log\left[\dfrac{0.3661\,(D+d)}{d}\right]}$$

$$\frac{\partial G}{\partial d} = \frac{\left(\dfrac{D}{D+d} \times \dfrac{1.0964\,d - 0.01401\,D}{d} - \dfrac{1.0964\,d - 0.02802\,D}{d} \times \log\left[\dfrac{0.3661\,(D+d)}{d}\right]\right)}{d^2\log^2\left[\dfrac{0.3661\,(D+d)}{d}\right]}$$

Letting $\dfrac{\partial G}{\partial d} = O$, in order to solve for the minimum value of G_{max}, we have

$$\log\left[\frac{0.3661\,(D+d)}{d}\right] - \frac{D}{D+d} \times \frac{d - 0.01278\,D}{d - 0.02556\,D} = O$$

which is satisfied when $D = 5.94\,d$. *Therefore, for three-conductor cables having equal belt and conductor insulation thicknesses, for a given core diameter, the minimum value of maximum stress will be attained when the conductor diameter equals the core diameter divided by* 5.94.

For a grounded neutral system it is not necessary to use the same amount of insulation between conductors and sheath as between conductors; common practise seems to indicate that for high-voltage grounded neutral systems the insulation to ground should not be less than 75 per cent of the insulation between conductors. With such cross-section there will usually be enough belt insulation to insure a reasonable factor of safety should some of the outer papers of the belt become damaged in the factory before lead covering, or be broken when the leaded cable is bent during reeling or during installation. For this case similar equations may be derived, and the most efficient cable, or the cable giving the minimum value of maximum stress is one where D equals $5.89 \times d$.

For low-voltage cables, where the stresses are usually low due to the relatively large thicknesses of insulation which have been considered good practise, some

cable makers use even slightly less insulation than this for the belt, and have insulation to ground as low as 70 per cent of the insulation between conductors. This is also the value given in British Engineering Standards Association in June 1919 for 11,000-volt paper cable and lower, and the thicknesses of conductor insulation recommended by these specifications are such as to bring the maximum stress fairly low, namely 24 kv. per cm. for 0.025 square inches, equivalent to about No. 4 A. W. G., when operating at 11 kv. three-phase. Even this is not the theoretical limit if we should attempt to design a cable whose stress toward the outside equals its maximum stress toward the center, but due to the fact that the belt is under severe mechanical strain and is likely to be broken and its insulating value impaired, it is probably not advisable to use less insulation to ground than 75 per cent and certainly not less than 70 per cent. For this amount of insulation, namely 70 per cent, we may also derive similar equations and obtain that, for minimum value of maximum stress, D equals $5.88 \times d$.

All the preceding facts and conclusions are based on three-conductor cables having round conductors. In case sector-shaped conductors are used, it is obvious that for a given core diameter we will have room for considerably more insulation and larger conductors. It is probable, however, that the increased curvature of the sector shape may increase the stress more rapidly than it would be diminished by the thicker possible insulation, and the result may very possibly be that sector cables will actually have lower limits of operating voltage for given limits of stress. A considerable amount of experimentation has been done on stresses in sector cables by the engineers of the company with which the writers are associated, and it is expected that the results of these experiments will be published in the near future. We may say for the present in regard to sector stresses that the stress may be either greater or less than the stress for a round conductor of the same area and with the same insulation thickness, depending upon the curvature of the sector. If the shape of the sector is such that the maximum stress is the same as for a circular conductor of the same cross-section, the saving in diameter will probably be about 5 per cent, or we may say that the limits of possible working voltage which we are about to give may be increased approximately 5 per cent if sector-shaped conductors are used.

It may be interesting to mention in passing certain results obtained by the writers experimentally in 1913, in connection with sector stresses. The stress in the inner third of the insulation around the conductor of a triplex cable was measured for various shapes of conductor. For the particular shape of sector used, it was found that the maximum stress for the sector-shaped conductor was 12.5 per cent greater than the maximum stress in the case of circular conductors, and the point of maximum stress for the sector conductor occurred at the two outer tips. Presumably if the stress had been measured at or near the conductor surface, this difference would have been greater.

There is of course another method of reducing the stresses in any type of cable, namely using successive layers of insulating materials of such permittivities that less voltage is impressed upon the inner layers of insulation. By this means, and with the available materials, we could possibly apply voltages of from 10 to 20 per cent higher than those about to be given, and still keep the maximum stress below the same limit.

MAXIMUM WORKING VOLTAGES FOR GIVEN LIMITS OF STRESS

As pointed out by the writers elsewhere[1], triplex paper cables are known to have operated for many years at stresses as high as *34.4 kv. per cm.*; rubber cables as high as *36.7 kv. per cm.*; and varnished cloth cables as high as *30.3 kv. per cm.* Since the present tendency appears to be to determine definitely upon some set limit of maximum stress as a matter of convenience in the design and rating of cables, it is of interest to select certain definite values such as 19.5 kv. per cm. as suggested by certain engineers[3], and say 25 kv. as suggested elsewhere by ourselves, and figure out the dimensions of the most efficient cables on these two assumptions.

If we know therefore what is the most efficient size of conductor for a given core diameter, and decide upon some maximum allowable stress, we may immediately determine the highest allowable working voltages for that core diameter. From the ratios calculated above, we have drawn curves for each type of triplex cable showing the minimum core diameter for the usual range of line voltages, if the stress is limited to certain values which we have taken arbitrarily as 19.5 and 25 kv. per cm. We have also calculated a similar curve for the form of cable suggested by Hochstadter commonly called type "H" cable, in which each single-conductor insulation is wrapped with copper foil, and the three cabled together without belt. In this case the usual single-conductor relation must hold that

$\frac{R}{r} = 2.718$ or e. For this cable the values of the curves were figured on the assumption that copper foil five mils in thickness was used. Fig. 4 shows one of these curves for a stress limit of 25 kv. per cm.

From these curves thus obtained, Table V has been prepared, showing the maximum voltages which may be employed for the usual sizes of duct if the stress is limited to these values. For each core diameter there is only one arrangement of size of conductor with corresponding insulation thickness which will give this stress, all other make-ups giving higher stresses. The

3. A .I. E. E. PROCEEDINGS, June 1919, Clark & Shanklin.

size of conductor and insulation thicknesses are also given in this table.

From Table V it can be seen that unless it be possible

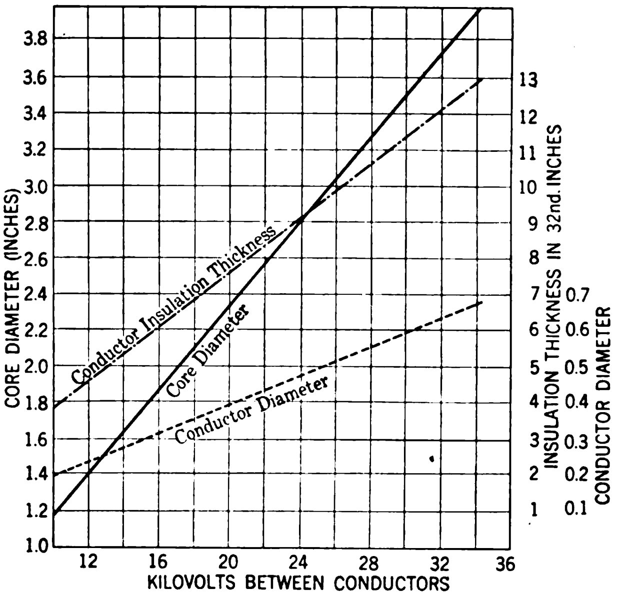


FIG. 4—CURVES SHOWING THE SMALLEST POSSIBLE TRIPLEX CABLES FOR THE USUAL RANGE OF HIGH-VOLTAGE CABLES, IF THE MAXIMUM STRESS IN THE INSULATION IS LIMITED TO 25KV. PER CM.

These curves are calculated for cables in which the belt insulation thickness is equal to the conductor insulation thickness.

Additional curves give for each voltage the size of conductor and insulation thickness which will produce the cable of minimum diameter.

to design cables to withstand higher stresses or to install larger ducts and manufacture and install larger cables, the highest possible three-phase working pressure for a triplex cable in an ungrounded neutral system is 23.3 kilovolts, if the maximum stress is limited to 19.5 kv. per cm., as suggested by certain experimenters, or 29.9 kilovolts if the maximum stress limit is 25 kv. per cm., at which stress many cables have operated successfully for as long as 20 years as pointed out by the writers elsewhere[1]. The above limits are for smooth round conductors, and are based solely on the assumption that maximum stress is the controlling factor rather than average stress, or stress in and near the filler spaces.

TABLE V

TABLE OF MAXIMUM WORKING VOLTAGES (EFFECTIVE VALUE) FOR TRIPLEX CABLES, IF THE MAXIMUM STRESS IS LIMITED TO CERTAIN VALUES

Width of duct. inches	Core diameter of cable in inches	Line kv. for stress of 19.5 per kv. per cm.	Line kv. for stress of 25 per kv. per cm.	Condr. diam. inches	Nearest size A.W.G.	Insulation thickness in 32nd in. Condr.	Insulation thickness in 32nd in. Belt	Type of cable
3	2.5	16.64	21.33	0.421	00	8.08	8.08	A
		18.57	23.80	0.425	"	9.56	4.78	B
		19.03	24.40	0.425	"	9.92	3.97	C
		18.15	23.27	0.423	"	11.63	0	D
3½	3	19.96	25.60	0.505	0000	9.70	9.70	A
		22.28	28.56	0.509	"	11.47	5.73	B
		22.84	29.27	0.510	"	11.90	4.76	C
		21.80	27.95	0.508	"	13.97	0	D
4	3.5	23.30	29.87	0.589	27,000	11.30	11.30	A
		26.00	33.33	0.594	cir.mils	13.38	6.69	B
		26.65	34.15	0.595	"	13.88	5.55	C
		25.44	32.61	0.594	"	16.33	0	D

A. Insulation to ground equals insulation between conductors.
B. Insulation to ground is 75 per cent of insulation between conductors.
C. Insulation to ground is 70 per cent of insulation between conductors.
D. Type "H" Cable.

For a grounded neutral system, where the insulation to ground is cut down to 70 per cent of the insulation between conductors, the corresponding figures are 26.7 kv. for 19.5 kv. per cm. stress, and 34.2 kv. for 25 kv. per cm. It is therefore obvious that, assuming as before that maximum stress is the controlling factor,

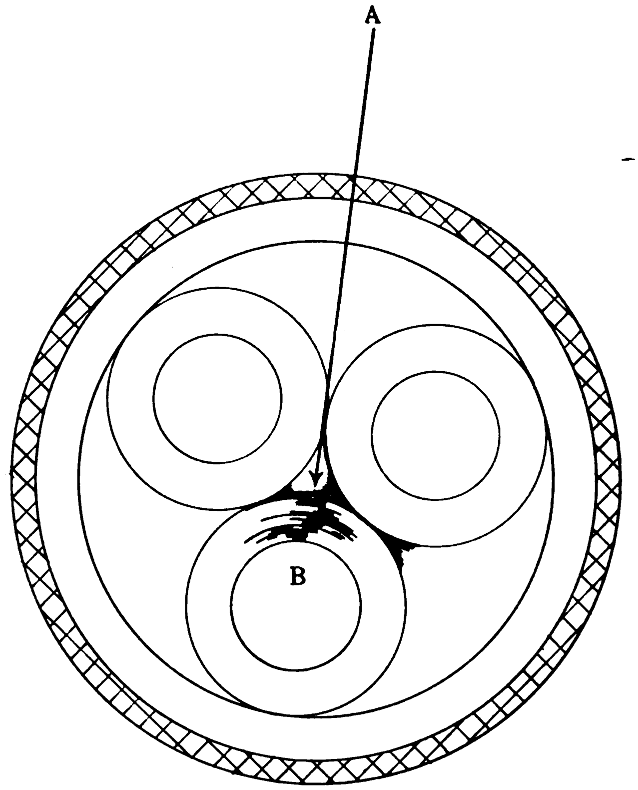


FIG. 5—EFFECT OF HIGH STRESS ON A TRIPLEX CABLE

three-conductor cables cannot operate at higher voltages than 34.2 kv. without exceeding the stress limits of 25 kv. per cm. unless we can manufacture larger cables and install them, or can develop insulations which can stand higher stresses.

The technical press has said more or less in recent years about charring of the center of triplex cables due to the combined heating effect of load current and high inherent dielectric loss in the insulation. Fig. 5 may be of interest as showing the appearance of a typical case of incipient failure of three-core cable operating without load but at such high three-phase voltage as would produce failure by ionization. The cable was subjected to a very high maximum stress for 126 hours while suspended in air at about 70 deg. fahr. The

cable was of mineral base compound and was of very low inherent dielectric loss even at high temperatures. It is believed that this drawing is of particular interest, since it shows not only the charring of the central filler, but also a case of incipient breakdown in the conductor insulation at the point of maximum stress. This drawing was built up very carefully, after the cable had been dissected layer by layer and drawings made of each layer, and it gives a very accurate representation of the amount of charring which was discovered.

It should be borne in mind, that the cable did not fail at this point, nor had any discharge taken place from A to B as there was no sign of puncture in any of the layers except one. It is worth noting that the charring, while perfectly discernible, was almost entirely confined to the surface of each layer of paper.

In the conclusion of their earlier paper [1], the authors stated that the data obtainable from actual operating cables would indicate that stresses as high as 40 kv. per cm. are permissible in single-conductor cables. There are many reasons why a single-conductor cable can stand a higher stress than a triplex cable. One of the chief reasons is that in a single-conductor cable the stresses are all normal to the surface of the paper layers, while in a triplex cable there are large tangential components of stress. One of the weakest points of a triplex cable is the filler space. While insulating materials have been greatly improved, the material available for use in the filler spaces has not kept pace with the rest of the insulation. Thus, at a relatively low stress at the surface of the conductor, the stress in and near the filler spaces may be far in excess of what the cable can stand. The single-conductor cable of course requires no fillers. Three-conductor cables made as suggested by Hochstadter, *i. e.* in which the insulation of each conductor is wrapped with copper foil, are essentially single-conductor cables insofar as the direction and magnitude of stresses are concerned, because the stresses are all radial and the filler spaces are unstressed; and it is reasonable to assume that they may operate at the same stresses which a single-conductor cable can stand. Besides, such cables can be operated at an even higher dielectric loss and higher current density than the ordinary three-core cable, due to the fact that the copper foil will conduct the heat away from the danger zone, namely the center of the cable. We may assume then, that this type of cable will eventually operate successfully for a long period of time at stresses in the neighborhood of 30 or 40 kv. per cm. or higher, since even three-conductor cables of the ordinary type have operated for years at values approximating those figures. In this case calculation shows that for 40 kv. per cm. stress, the maximum line voltages possible for three-conductor Type "H" cable are 37.3 kv. for 2½-inch core diameter, 44.8 kv. for 3-inch core diameter, and 52.3 kv. for 3½-inch core diameter.

Conclusions

It may be reasonably concluded from the limits shown in this article that for the high-voltage cables of the future, the ordinary three-core form of cable will be used as heretofore up to 30,000 volts, except where replaced by cable of higher efficiency; type "H" cable on account of its high carrying capacity, and high permissible working stress, from a few kilovolts up to 50,000 volts; and three single-conductor cables with conductors made with a hollow fibre core to increase the conductor diameter, for 50,000 volts and above. Three single-conductor cables could of course be used at lower ranges than this, but due to the difficulties of induced sheath currents and voltages and their higher cost, they would probably not be good economy until the higher voltage limit is reached, unless such large amounts of power are involved, as would require more than three triplex cables of the maximum size considered practical.

We desire to express our thanks to Mr. R. W. Atkinson for his suggestions and assistance in preparing the text.

APPENDIX A

Maximum Stress in Single-Conductor Cables

Let us find the stress in a 0000 strand single-conductor cable insulated with a thickness of 11/32 in. and 13,200 volts pressure. The diameter of a 0000 strand conductor equals 0.528 in., and 11/32 in. equals 0.3438 in. The ratio of conductor insulation thickness to conductor diameter therefore equals 0.651. The ordinate corresponding to this value in Curve A, Fig. 1 is 0.156. The average stress in this cable equals

$$\frac{13.2}{2.54 \times 0.3438} = 15.12 \text{ kv. per cm.}$$

15.12×0.156 equals 23.6 kv. per cm. maximum stress.

APPENDIX B

Maximum Stress in Triplex Cables

The maximum stress in a triplex cable occurs at the surface of the conductor at the point nearest the center or axis of the cable. Let us calculate the maximum stress in a three-conductor cable, 0000 strand, insulated with 9/32-in. insulation on each conductor and 9/32-in. belt, at 25,000 volts working pressure. Note that the maximum stress occurs toward the center of the cable, and is practically independent of the belt thickness. The diameter of a 0000 A. W. G. strand conductor equals 0.528 in., and 9/32 in. equals 0.281 in. Applying formula (1), we obtain 0.366 as the distance between the conductor surface and the center of the cable. As stated in the body of the article the maximum stress of the triplex cable is equal to the maximum stress in a single-conductor cable whose conductor diameter is the same as that of the triplex conductor and whose insulation thickness is equal to

the distance between the surface of the conductor and the center of the triplex cable, this value of stress thus obtained being mutiplied by a final correction factor. We must therefore determine the maximum stress in a single-conductor cable whose conductor diameter is 0.528 in., and whose insulation thickness is 0.366 in. This can be done by the usual formula or more conveniently by Curve *A* in Fig. 1. Choosing the latter method, the ratio of conductor insulation thickness to conductor diameter,

$$\frac{0.366}{0.528} = 0.693$$

The ordinate of Curve *A*, Fig. 1, corresponding to this, equals 1.592. The average stress of this insulation equals

$$\frac{25 \text{ kv.}}{\sqrt{3} \times 2.54 \times 0.366} = 15.5 \text{ kv. per cm.}$$

The maximum stress, therefore, equals

$$15.5 \times 1.592 = 24.7 \text{ kv. per cm.}$$

As mentioned above, however, there is a final correction factor to this value, depending upon the ratio of the *actual* conductor insulation thickness and conductor diameter, which ratio in this case,

$$\frac{0.281}{0.528}, \text{ equals } 0.532.$$

Interpolating between the values of the correction factor in the body of the article, we find that for this ratio the correction factor equals 1.02. The maximum stress in the triplex cable therefore is 1.02 × 24.7, which equals 25.2 kv. per cm.

APPENDIX C

Stress toward the Sheath in Triplex Cables

As an example let us find the stress at that portion of the surface of the conductor which is toward the sheath, in the triplex cable whose maximum stress was calculated in Appendix B, namely 0000 A. W. G. insulated with 9/32 in. on each conductor and 9/32-in. belt. The total insulation between conductors and ground equals 18/32 or 0.5625 in. The ratio of total insulation thickness to conductor diameter,

$$\frac{0.5625}{0.528} = 1.065.$$

The ordinate of Curve *B*, Fig. 1, corresponding to this value equals 1.745. The average stress is

$$\frac{25 \text{ kilovolts}}{\sqrt{3} \times 2.54 \times 0.5625} = 10.1 \text{ kv. per cm.}$$

This stress therefore equals

$$10.1 \times 1.745 = 17.6 \text{ kv. per cm.}$$

NEW ZEALANDS TELEGRAPH SERVICE

New Zealand is giving the rest of the world a good race in the perfection of its telephone and telegraph systems. Mr. E. A. Shrimpton, M. I. E. E., Permanent Chief Engineer of the Telegraph and Telephone Department of states that at the present time there are 85,000 telephones in use in New Zealand, an average of one to every sixteen inhabitants. Subscription to the phone system has never been solicited, a fact which makes the figures more to be wondered at.

The little island outpost of the British Empire takes particular pride in the fact that it has developed its lines of communication to such an extent while the British Isles can only boast of one telephone to about every forty-seven persons. Telephone rates in New Zealand have been increased this year without in any way decreasing the demands of new subscribers.

In an interview at the offices of the Western Electric Co., Mr. Shrimpton gave an interesting history of the development of the lines of communication in New Zealand. The first telephone exchange was erected at Christ Church only in 1880 yet today there are 400 exchanges in a country of only 1,100,000 people. There is not a single spot in New Zealand where the pedestrians cannot find a telephone line. There has even been a line to The Hermitage at the peak of New Zealand's loftiest mountain, nuch to the regret of the tired business men who had been accustomed to flee there to escape the humdrum of office life.

New Zealand has sent Mr. Shrimpton to the United States to investigate the latest developments in telephone and telegraph apparatus. In 1911 the new automatic exchange system was introduced into his department. Since the war 23 rotary automatic exchanges have been or will be put into use in New Zealand.

The New Zealanders are said to be the greatest telegraph users in the world. During 1919 their telegraph lines carried over 14,000,000 messages, a far higher average than prevailed in the United States. At the present time New Zealand has supervision over all the British wireless stations in the Pacific. In addition to five in its own territory, Mr. Shrimpton's department controls the stations at Chatham Island, Apia and Raratonga. Before the war the station at Apia belonged to Germany. It is over 1800 miles away from headquarters at New Zealand.

On Electrostatic Transformers and Coupling Coefficients.*

BY F. C. BLAKE

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Starting from the experimentally determined fact that the capacity of an air condenser is independent of the frequency of electrical oscillation, it is shown by means of Lord Rayleigh's equations for the mutual reaction between two circuits each having inductance, resistance, and capacity, that for high-frequency conditions when the resistance is negligible compared to the reactance, the capacity reaction between the two circuits can be expressed best in terms of elastances. Definitions are given for self and mutual elastances as well as for self and mutual capacitances and the definitions are tested by our knowledge of spherical condensers. The coefficient of elastic coupling is shown to be the ratio between the mutual elastance and the square root of the product of the two self elastances, the analogy with the coefficient of inductive coupling being exact. The coefficient of capacitive coupling between two circuits each having capacity with a capacity in the branch common to both is shown to be a limiting case of the coefficient of elastic coupling, and thereby a condenser of the ordinary or close form is shown to be an electrostatic transformer with a coupling coefficient of unity. The true relationship between Maxwell's coefficients of capacity and the elastances or capacitances is pointed out in the case of the spherical condenser. The ideas developed are applied to the thermionic tube and thereby the behavior of the ultraudion and the experiments of Van der Pol are readily explained. Attention is called to the alternative view of the behavior of condensers toward alternating currents, viz., instead of being paths of low impedance, they are paths of ready yielding or low stiffness or elastance, as suggested by Heaviside and by Karapetoff.

In a paper presented before the American Physical Society in November 1919, the writer was able experimentally to verify the equations developed by Lord Rayleigh[1] for the reaction of one circuit upon another, each circuit having both kinetic and potential energy as well as dissipation, *i. e.*, inductance, capacity and resistance. If L_{11}, L_{22} and L_{12} are the self and mutual inductances, E_{11}, E_{22} and E_{12} the self and mutual elastances, (see below) R_{11}, R_{22} and R_{12} the self and mutual resistances, and p the generalized frequency, then the effective elastance, E_e and the effective resistance, R_e are given by the equations:

$$E_e = E_{11} - p^2 L_{11} - \frac{(E_{12} - p^2 L_{12})^2}{E_{22} - p^2 L_{22}} + \frac{p^2 [R_{12}(E_{22} - p^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{(E_{22} - p^2 L_{22})[(E_{22} - p^2 L_{22})^2 + p^2 R_{22}^2]}, \quad (1)$$

$$R_e = R_{11} - R_{12}^2/R_{22} + \frac{[R_{12}(E_{22} - p^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{R_{22}[(E_{22} - p^2 L_{22})^2 + p^2 R_{22}^2]}. \quad (2)$$

The verification was accomplished by working with Lecher and receiver systems, thus using short electric waves. For such systems the distributed capacity of the Lecher wires has to be taken into account as well as the capacities of the condensers. Thus the generalized formula for the discharge of a condenser was found to hold, *viz.*,

$$\frac{2\pi l}{\lambda} \tan \frac{2\pi l}{\lambda} = \frac{k l}{K}, \quad (3)$$

where l is the length of the Lecher circuit measured from the exploring bridge up to the condenser, λ the wave-length of the harmonic under consideration, K the capacity of the condenser and k the capacity per unit length of the Lecher wires. In such systems equation (3) takes the place of Lord Kelvin's equation for the discharge of a condenser, *viz.*,

$$p^2 L K - 1 = 0. \quad (4)$$

In equations (1) and (2) all the self coefficients were determined from geometrical considerations, the mutual coefficients being determined from the experimental observations. For instance, E_{11} is the reciprocal of the capacity of the plate attached to the Lecher circuit when it exists *alone in space*, E_{22} being the reciprocal of the capacity of the plate attached to the receiver circuit *under the same conditions*. E_{12} on the other hand was determined by noting the difference in frequency of the two fundamental tones as the coupling between Lecher and receiver circuits was tightened. Similarly, L_{11} is the self inductance of half of the Lecher circuit and L_{22} is the self inductance of the receiver circuit. Substituting these values of L and E in equation (3) one can find the natural frequency n of each circuit *when alone in space*. It is, of course, this natural frequency n that must be used in equations (1) and (2) for either primary (Lecher) or secondary (receiver) circuit when existing separately. Hence, equations (1) and (2) become

$$E_e = E_{11} - n^2 L_{11} - \frac{(E_{12} - p^2 L_{12})^2}{E_{22} - n^2 L_{22}} + \frac{p^2 [R_{12}(E_{22} - n^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{(E_{22} - n^2 L_{22})[(E_{22} - n^2 L_{22})^2 + p^2 R_{22}^2]}, \quad (5)$$

$$R_e = R_{11} - \frac{R_{12}^2}{R_{22}} + \frac{[R_{12}(E_{22} - n^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{R_{22}[(E_{22} - n^2 L_{22})^2 + p^2 R_{22}^2]}. \quad (6)$$

*Read before the American Physical Society, Feb. 28, 1920.

1. *Phil. Mag.* XXI. pp. 369-381, 1886; Scientific Papers, Vol. II p. 484.

By causing the Lecher and receiver circuits to approach each other both E_{12} and R_{12} were made to vary, the system being so disposed that L_{12} was practically zero always. Naturally E_{12} would be expected to increase and R_{12} to decrease as the circuits approached each other. This was borne out by observation. Calculation really showed that for the frequencies used ($n > 10^8$) the last term in (**5**) was negligible compared to the other terms so long as R_{12} was small. Because the currents are of such high frequency $p^2 R_{22}^2$ is entirely negligible compared to $(E_{22} - n^2 L_{22})^2$ and (**5**) and (**6**) reduce to

$$E_e = E_{11} - n^2 L_{11} - \frac{(E_{12} - p^2 L_{12})^2}{E_{22} - n^2 L_{22}} + \frac{p^2 [R_{12}(E_{22} - n^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{(E_{22} - n^2 L_{22})^3}, \quad (7)$$

$$R_e = R_{11} - \frac{R^2_{12}}{R_{22}} + \frac{[R_{12}(E_{22} - n^2 L_{22}) - R_{22}(E_{12} - p^2 L_{12})]^2}{R_{22}(E_{22} - n^2 L_{22})^2}. \quad (8)$$

For distances between the circuits less than 15 per cent of the diameter of the capacity plates it was found that R_{12} was practically equal to zero and (**7**) reduced in this case to

$$E_e = E_{11} - n^2 L_{11} - \frac{(E_{12} - p^2 L_{12})^2}{E_{22} - n^2 L_{22}}.$$

For electrostatic (elastic) coupling between the circuits L_{12} is zero and we have

$$E_e = E_{11} - n^2 L_{11} - \frac{E_{12}^2}{E_{22} - n^2 L_{22}}. \quad (9)$$

Thus for radio frequency currents the effective elastance of a circuit is apparently a function not only of its own elastance, the elastance of a neighboring circuit and their mutual elastance but also of their self and mutual inductances. If now the self (C_{11} and C_{22}) and mutual (C_{12}) capacitances of the conductors forming the condensers between the Lecher and receiver circuits be *defined* as the reciprocals of the self and mutual elastances of these conductors and if C_e be the effective capacity of the primary circuit, then

$$C_e = C_{11} \frac{1}{(1 - n^2 L_{11} C_{11}) - \frac{C_{11} C_{22}}{C_{12}^2} \cdot \frac{1}{1 - n^2 L_{22} C_{22}}}. \quad (10)$$

If in (**9**) the inductances L_{11} and L_{22} are negligible or zero we have

$$E_e = E_{11} - \frac{E_{12}^2}{E_{22}}, \quad (11)$$

which is, of course, the effective capacity of a conductor in the presence of another conductor for high-frequency currents. It is to be noted that equation (**11**) is the exact analog for reacting systems having stiffness or elastance, of the well-known equation for inductively reacting systems, *viz.*,

$$L_e = L_{11} - \frac{L_{12}^2}{L_{22}}. \quad (12)$$

Now inertia (inductance) is a measure of the resistance a body offers to a change in its condition of motion, and stiffness (elastance) is a measure of the resistance an elastic body offers to its instantaneous condition of vibratory motion. If in (**12**) the coefficient of inductive coupling k is equal to $\frac{L_{12}}{\sqrt{L_{11} L_{22}}}$ as is well-known, then (**12**) may be written $L_e = L_{11}(1 - k^2)$. (**13**) So also the coefficient of elastic coupling k is equal to $\frac{E_{12}}{\sqrt{E_{11} E_{22}}}$ and (**11**) may be written

$$E_e = E_{11}(1 - k^2) \quad (14)$$

From the definitions of self and mutual capacitances given it is manifest that if in (**10**) we take L_{11} and L_{22} each zero the effective capacity of the primary circuit becomes

$$C_e = C_{11} \frac{C_{12}^2}{C_{12}^2 - C_{11} C_{22}}, \quad (15)$$

and if we substitute k^2 for $\frac{C_{11} C_{22}}{C_{12}^2}$ (**15**) reduces to

$$C_e = \frac{C_{11}}{1 - k^2}, \quad (16)$$

which obviously may be made as large as we please by making k approach unity more and more nearly. This accounts for the capacity of a condenser being so enormous compared to the capacities of its component conductors when far removed from each other.

Just as in (**13**) the maximum value of k is unity so the maximum value of k in (**14**) is also unity. Thus just as the effective inductance of a coil is decreased by the presence of a second coil so also the effective elastance of a conductor is decreased by the presence of a second conductor.

In discussing two mutually reacting inductive circuits Lord Rayleigh derives the equation

$$L_e = L_{11} - \frac{L_{12}^2}{L_{22}} + \frac{(L_{12} R_{22} - L_{22} R_{12})^2}{L_{22}(p^2 L_{22}^2 + R_{22}^2)}, \quad (17)$$

in which the second fraction is positive and with increasing p^2 continually diminishes. Hence, Lord Rayleigh remarks that L_e continually diminishes with increasing frequency tending ultimately to the minimum corresponding to the disappearance of the dissipative terms. At radio frequencies this minimum has been reached and (**17**) then reduces to (**12**). If in

(**5**) and (**6**) we have two mutually reacting elastic circuits the, taking $L_{12} = 0$, (**5**) and (**6**) become

$$E_e = E_{11} - \frac{E_{12}^2}{E_{22}} + \frac{p^2 (R_{12} E_{22} - R_{22} E_{12})^2}{E_{22} (E_{22}^2 + p^2 R_{22}^2)} \quad (18)$$

$$R_e = R_{11} - \frac{R_{12}^2}{R_{22}} + \frac{(R_{12} E_{22} - R_{22} E_{12})^2}{R_{22} (E_{22}^2 + p^2 R_{22}^2)}, \quad (19)$$

and Lord Rayleigh remarks for this case of the discharge of condensers through high resistances that as p^2 increases the elastance increases and the resistance diminishes. But here again at radio frequencies the resistance terms disappear compared to the reactance terms unless unusually fine discharge wires are used and accordingly the third term on the right-hand side of (**18**) becomes negligible and again the minimum given by the first two terms has been reached and (**18**) reduces to (**11**). In other words, beyond a certain frequency the effective elastance, instead of increasing with increasing frequency as Lord Rayleigh says, will in general decrease owing to the ratio of the reactance to the resistance steadily mounting in value, the effective elastance ultimately reaching the minimum given by the disappearance of the dissipative terms.

Comparison of (**11**) with (**12**) and of (**13**) with (**14**) leads to the following further considerations. Given two inductive coils *each on closed circuit.* Starting with them infinitely removed from each other, by causing the distance between them to decrease from infinity to zero the coefficient of inductive coupling is increased from zero to unity. When alone in space the self inductance of each coil is the magnetic flux from it (through it) when unit current is passing in it. So also for any given distance between the two coils the mutual inductance is the magnetic flux through one coil due to unit current in the other. Similarly, given two conductors infinitely removed from each other to start with. As the distance between them is decreased from infinity to zero the coefficient of elastic coupling is increased from zero to unity. When each conductor is alone in space its self elastance is the electric flux from it due to unit charge upon it. So also for any given distance between the two conductors their mutual elastance is the electric flux ending on one conductor B due to unit charge on the other A provided the conductor B has the induced charge of like sign as that on A removed by being "earthed."

That the proviso in this definition of mutual elastance is necessary is easily shown from a consideration of the spherical condenser. It has been shown (equation **15**) that the theoretical capacity of a condenser is the reciprocal of the effective elastance, E_e, where E_e fulfills equation (**11**). Now it is well-known that if a and b are the radii of the inner and outer spheres of a spherical condenser the capacity of the condenser when the outer sphere is earthed is $\frac{a\,b}{b-a}$ and when the inner sphere is earthed its capacity is $\frac{b^2}{b-a}$. If the inner sphere is taken as the first conductor and the outer sphere as the second then we have $E_{11} = 1/a$ and $E_{22} = 1/b$ whence

$$\frac{b-a}{a\,b} = \frac{1}{a} (1 - a\,b\,E_{12}^2), \quad (20)$$

giving $E_{12} = 1/b$ and consequently $C_{12} = b$. Thus $k = \sqrt{a/b}$ and when $b = \infty$ $k = 0$ and for $b = a$, $k = 1$ as it should. If the conductors be reversed we get

$$\frac{b-a}{b^2} = \frac{1}{b} (1 - a\,b\,E_{12}^2),$$

giving $E_{12} = 1/b$ as before. The fact that for the spherical condenser $E_{12} = E_{22}$ testifies most strikingly to one of its fundamental properties, *viz.*, that all the lines of force leaving the inner sphere end on the inner surface of the outer sphere.

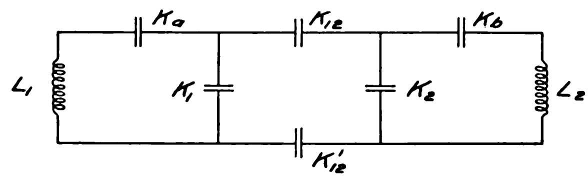

FIG. 1

It is customary to define the capacity of a condenser as the ratio of the charge on one of the conductors forming the condenser to the difference of potential between the conductors, all the lines of electric flux starting from one conductor ending on the other. The last phrase of the previous sentence shows that such a condenser *is to be regarded as an electrostatic transformer whose coefficient of elastic coupling is unity.*

It will now be shown that the coefficient of elastic coupling as defined in this paper, *viz.*, the ratio of the mutual elastance between the two component conductors of a condenser divided by the square root of the product of their self elastances enables one at once to derive the coefficient of electrostatic coupling between two circuits in each of which there is a condenser with a third condenser in the branch common to both circuits.

E. Bellini[2] has shown that the coefficient k of what he calls the electric coupling fulfills for the most general case (see Fig. 1) the equation

$$k = \frac{K_t}{K_1 K_2} \sqrt{G_1 G_2}, \quad (21)$$

2. *La Lumière Electrique*, 2, 33, p. 241, 1916.

where

$$\frac{1}{K_t} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_{12}} + \frac{1}{K_{12}'},$$

$$\frac{1}{G_1} = \frac{1}{K_a} + \frac{1}{K_1} - \frac{K_t}{K_1^2},$$

and

$$\frac{1}{G_2} = \frac{1}{K_b} + \frac{1}{K_2} - \frac{K_t}{K_2^2}.$$

By taking

$$K_{12} = K_{12}' = \infty, \; k \text{ reduces to } \frac{\sqrt{K_{11} K_{22}}}{K_c} \tag{22}$$

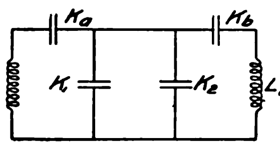

FIG. 2A

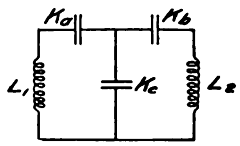

FIG. 2B

where

$$\frac{1}{K_{11}} = \frac{1}{K_a} + \frac{1}{K_c} \text{ and } \frac{1}{K_{22}} = \frac{1}{K_b} + \frac{1}{K_c}$$

and

$$K_c = K_1 + K_2.$$

In this case Fig. 1 obviously reduces to Fig. 2A, and Professor G. W. O. Howe[3] has shown that Fig. 2A reduces to Fig. 2B wherein

$$K_c = K_1 + K_2$$

Consider now Figs. 3 and 4.

The two figures are exactly alike except that in Fig. 3 the reaction is an inertia reaction while in Fig. 4, it is an elastic reaction, hence the conductors E_1 and E_2 are represented as spiral springs while the L's may

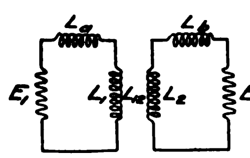

FIG. 3

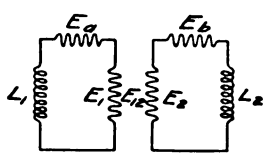

FIG. 4

be thought of as masses if one chooses. Plainly the coefficient of magnetic coupling k in Fig. 3 is given by

$$k^2 = \frac{L_{12}^2}{L_{11} L_{22}}$$

where $L_{11} = L_1 + L_a$ and $L_{22} = L_2 + L_b$

Equally plainly in Fig. 4 the coefficient of elastic coupling k is given by

$$k^2 = \frac{E_{12}^2}{E_{11} E_{22}}$$

where $E_{11} = E_1 + E_a$ and $E_{22} = E_2 + E_b$

3. *Electrical World*, 68, p. 368, 1916.

Accordingly remembering the reciprocal relationship between elastances and capacitances we have

$$k^2 = \frac{E_{12}^2}{E_{11} E_{22}} = \frac{\frac{1}{C_{12}^2}}{\frac{1}{C_{11}} \frac{1}{C_{22}}}$$

$$= \frac{E_{12}^2}{(E_a + E_1)(E_b + E_2)}$$

$$\frac{\frac{1}{C_{12}^2}}{\left(\frac{1}{C_a} + \frac{1}{C_1}\right)\left(\frac{1}{C_b} + \frac{1}{C_2}\right)} \tag{23}$$

If one redraws Fig. 2B as Fig. 5 by omitting the inductances it is readily seen that the system consists of four circuits, two of which are exact counterparts of the other two. Viewed from the standpoint of a Lecher system, circuits 1 and 2 of Fig. 5 are equal, as

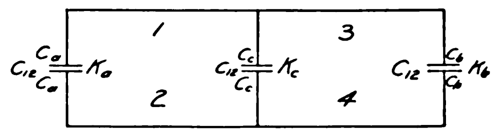

FIG. 5

are also circuits 3 and 4. But by comparing Figs. 4 and 5 we see at once that on account of (**16**)

$$k_a = \frac{C_a}{1 - k^2}, \; k_c = \frac{C_c}{1 - k^2}, \text{ and } k_b = \frac{C_b}{1 - k^2}.$$

Now E_1 of Fig. 4 is $\frac{1}{C_c}$ of Fig. 5 as is also E_2 of Fig. 4. Whence

$$k^2 = (1 - k^2)^2 \frac{\frac{1}{C_{12}^2}}{\left(\frac{1}{k_a} + \frac{1}{k_c}\right)\left(\frac{1}{k_b} + \frac{1}{k_c}\right)}$$

$$k = (1 - k^2) \frac{\frac{1}{C_{12}}}{\sqrt{\left(\frac{1}{k_a} + \frac{1}{k_c}\right)\left(\frac{1}{k_b} + \frac{1}{k_c}\right)}} \tag{24}$$

But k_c (Fig. 5) $= \frac{C_c}{1 - k^2}$

whence

$$k = \frac{C_c}{C_{12}} \frac{\frac{1}{k_c}}{\sqrt{\left(\frac{1}{k_a} + \frac{1}{k_c}\right)\left(\frac{1}{k_b} + \frac{1}{k_c}\right)}}$$

$$= \frac{C_c}{C_{12}} \cdot \frac{\sqrt{K_{11} K_{22}}}{k_c},$$

which is equation (**22**) provided $\frac{C_c}{C_{12}}$ may be taken equal to unity, a permissible thing to do for ordinary condensers, as has been shown. Thus it is proved that the coefficient of electric or electrostatic coupling is identical for very close couplings with the coefficient of elastic coupling. It is thus seen that just as the auto transformer is the limiting case of the customary transformer (See Circular No. 74, B. S. p. 49, Figs. 33A and B) so also the auto condenser transformer (Fig. 33C of B. S. 74 or Fig. 2 of this paper) is the limiting case of Fig. 4 of this paper. W. O. Lytle has recently[4] verified experimentally equation (**22**).

Several practical consequences follow from the above considerations. This paper gives, as it were, the modus operandi of the capacity coupling of a triode valve. It explains for instance the regenerative action of deForest's ultraudion connection,[5] for there is elastic coupling between the grid and plate and also between the plate and filament of a triode valve as

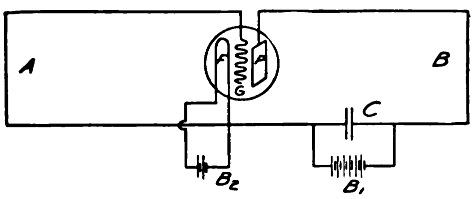

Fig. 6

indeed between the grid and filament. Hence deForest's explanation and that of Armstrong on the action of this circuit do not differ so much after all.

That regeneration can occur under much simpler conditions than that given in the ultraudion has been proved lately by B. Van der Pol, jr.[6] Indeed his circuits $P\,B\,C$ and $G\,A\,C$ (Fig. 6) may be thought of as Lecher and receiver circuits respectively of a Lecher system. Evidently many writers and experimenters[7] are conscious of the existence of a capacity coupling between the grid and the plate of a triode valve though no one seems to have attempted before to explain the nature of this coupling. Van der Pol even remarks that varying the distance between the plates of the external condenser not only varies the capacity in the plate circuit but also the coupling coefficient. In the light of this paper this is readily understood.

It might at first sight appear from equation (**9**) that the effective elastance of a condenser is a function of the electrical constants of the discharge wires with which it happens to be associated. The terms containing the inductances of the primary and secondary circuits have been introduced into the equation to allow for the distributed capacity of the discharge wires. The writer has proved by experiment that the effective elastance of an air condenser is independent of frequency. For circular plates 5 cm. in diameter and 1 mm. thick the mutual elastance E_{12} was determined experimentally by observing the two fundamental wave-lengths λ_1 and λ_2 that existed in the Lecher system when the coupling became tight enough to produce two. Thus k was equal[8] to $\frac{\lambda_2^2 + \lambda_1^2}{\lambda_2^2 - \lambda_1^2}$ and this was set equal to $\frac{E_{12}}{\sqrt{E_{11}\,E_{22}}}$ and E_{12} thereby determined. It is possible to determine E_{12} theoretically from (**11**) or (**14**) in certain simple cases as has been done above for the spherical condenser. In all such cases, however, the capacity of the discharge wires has been ignored and any theoretical value of k or E_{12} could not be expected to agree with the value obtained by experiment. For instance for the plates mentioned above when separated 6.84 mm., k was found to be 0.2243 and since $E_{11} = E_{22} = 0.6109$ e. s. u. E_{12} was found to be 0.1371 e. s. u., and thus E_e was 0.3090 e. s. u. But if the E_e is independent of frequency it is plain that what happens when one attempts by experiment to determine k is that the λ_1 and λ_2 necessarily so change as to hold E_e independent of n and thus the measured value of k and hence E_{12} are lower than the theoretical value just in proportion to the effect of the distributed capacity of the Lecher wires. Thus while E_e is not a function of the inductance of the Lecher wires it is because λ_1 and λ_2 are such as *necessarily* to compensate for what would otherwise appear to be the influence on E_e in equation (**9**) of L_{11} and L_{22}, n being connected with the inductances through equation (**3**). Thus what *does* change with the electrical constants of the discharge wires is the coupling coefficient, being much reduced from the theoretical value because of their distributed capacity. Should one attempt to determine experimentally, for instance, the coupling coefficient between the grid and plate of a thermionic tube he would find it a function of the electrical constants of the plate and grid circuits. Should one represent

$$\frac{E_{12}^2}{(E_{11} - n^2 L_{11})\,(E_{22} - n^2 L_{22})}$$

by k^2, equation (**9**) could be written

$$E_e = (E_{11} - n^2 L_{11})\,(1 - k_1^2), \qquad (25)$$

Whence

$$k_1^2 = \frac{k^2 E_{11} - n^2 L_{11}}{E_{11} - n^2 L_{11}} \qquad (26)$$

For the plates mentioned above, k_1^2 would equal $1 - \frac{E_e}{E_{11} - n^2 L_{11}} = 0.144$ whence $k_1 = 0.338$, and if one substitutes the value of E_e and E_{11} in (**14**) k would

4. *Proc.* Inst. Rad. Eng. 7, p. 427, 1919.

5. See Goldsmith's Radio-telephony, p. 91; also *Proc.* I. R. E. 4pp. 264-6, 1916.

6. *Phil. Mag.* 38, p. 90, 1919.

7. Notably Hazeltine, Armstrong and Van der Pol, jr.

8. See for instance Fleming's Principles of Electric Wave Telegraphy, 2nd Edition, p. 262.

equal 0.702 instead of 0.224 and E_{12} would equal 0.429 instead of 0.137.

Future experimentation alone can determine under what conditions it is important to know the coupling coefficients of a thermionic tube. Equation (**26**) shows, however, that k_1 equals k when both are equal to unity, or in other words when the distributed capacity of the discharge wires can be neglected compared to the condenser capacity. In radio practise one generally employs condensers of large capacity and hence by masking the internal coupling coefficient of a thermionic tube by an outside coupling of unity one reduces the need for knowing the internal coefficient. And yet in Van der Pol's experiments he found oscillation set in when the plates of his external condenser (10-cm. diameter) were 1 cm. apart. Since the ratio of the distance between the plates to their diameter did not differ much from the experiments of the writer, and the capacity and inductance of the external circuits were of about the same magnitude as those of Lecher circuits used by the writer, it is likely that the coefficient of coupling at the moment of oscillation in his experiments was not far from 0.25. Certain types of thermionic tubes, *e. g.*, deForest's "laboratory oscillion," have the ratio of the distance between the grid and plate to the mean diameter of plate not far different from 0.1 and hence their coupling coefficient must in general be distinctly less than unity. Other types are still more open. Van der Pol's experiments seem to call in question the statement made by Miller[9] that the input resistance of a thermionic tube is always positive for a capacity load, for Van der Pol with such a load actually had the tube working as an oscillation generator.

It might be well to point out certain properties of self and mutual elastances and capacitances of conductors as compared with Maxwell's coefficients of potential and capacity. If q_1 and q_2 are charges and v_1 and v_2 potentials then we have Maxwell's well-known equations

$$\left.\begin{aligned} q_1 &= k_{11} v_1 + k_{12} v_2 \\ q_2 &= k_{12} v_1 + k_{22} v_2 \end{aligned}\right\} \tag{27}$$

where k_{11}, k_{22} and k_{12} are capacity coefficients and

$$\left.\begin{aligned} v_1 &= c_{11} q_1 + c_{12} q_2 \\ v_2 &= c_{12} q_1 + c_{22} q_2 \end{aligned}\right\} \tag{28}$$

where c_{11}, c_{22} and c_{12} are coefficients of potential. Maxwell long ago pointed out that all the c's are positive while k_{11} and k_{22} are positive but k_{12} is negative. Now when the second conductor is absent c_{11} is the self elastance, but in general c_{11} as well as c_{12} and c_{22} in (**28**) changes as the two conductors approach each other. So also in (**27**) all the k's are functions of the distance between the conductors and so k_{11} is the self capacitance of the first conductor only when the second conductor is absent. Accordingly there is no justification for calling k_{11} and k_{22} coefficients of (self) capacitance and k_{12} a coefficient of mutual capacitance as is sometimes done. Of course the geometrical configuration of the system of two conductors must enable one to work out the exact relationship between Maxwell's coefficients and the elastances or capacitances for any particular case, *e. g.*, for the spherical condenser given above. For this condenser it is known that $k_{11} = \dfrac{a\,b}{b - a} = -\,k_{12}$ and $k_{22} = \dfrac{b^2}{b - a}$. And it has been shown that $C_{11} = a$ and $C_{12} = b = C_{22}$.

$$\left.\begin{aligned} &\text{Hence} \quad k_{11} = \frac{C_{11}\,C_{22}}{C_{22} - C_{11}}, \; k_{12} = \frac{-\,C_{12}\,C_{11}}{C_{22} - C_{11}} \\ &\text{and} \quad k_{22} = \frac{C_{22}^2}{C_{22} - C_{11}} \\ &\text{or} \quad k_{11} = \frac{1}{E_{11} - E_{22}}, \; k_{12} = \frac{-\dfrac{E_{22}}{E_{12}}}{E_{11} - E_{22}} \\ &\text{and} \quad k_{22} = \frac{\dfrac{E_{11}}{E_{22}}}{E_{11} - E_{22}} \end{aligned}\right\} \tag{29}$$

Those interested have here enough to keep them busy for some time. There is, however, one relationship for infinite distance between conductors that deserves comment. Eliminating the q's and v's between (**27**) and (**28**) one obtains

$$\frac{1 - k_{11}\,c_{11} - k_{12}\,c_{12}}{k_{12}\,c_{11} + k_{22}\,c_{12}} = \frac{k_{11}\,c_{12} + k_{12}\,c_{22}}{1 - k_{12}\,c_{12} - k_{22}\,c_{22}}. \tag{30}$$

If we now put

$k_{11} = k_{22}$ and $c_{11} = c_{22}$ (**30**) reduces to

$$k_{12} = \frac{1}{c_{11} + c_{12}} - k_{11}. \tag{31}$$

With conductors infinitely removed from each other

$$c_{11} = \frac{1}{k_{11}} = E_{11} = \frac{1}{C_{11}} \text{ and } c_{12} = 0 = E_{12}$$

$$= \frac{1}{C_{12}} \text{ hence } k_{12} = 0 \text{ also.}$$

Thus the mutual capacitance is infinity in this case, whereas Maxwell's coefficient of induction (sometimes called the mutual capacitance) is (negative) zero.

In many ways it seems more fundamental to express k^2 as $\dfrac{E_{12}^2}{E_{11}\,E_{22}}$ rather than as $\dfrac{C_{11}\,C_{22}}{C_{12}^2}$ and to this extent the idea of elastance is more fundamental than the idea of capacitance. Hazeltine[10] has pointed out, however, one important difference between electrostatic (elastic) coupling and magnetic coupling.

9. Bureau of Standards, Sci. Paper 351, 1919.

Magnetic couplings may be normal or reversed; not so elastic couplings. If desirous one would be permitted of course to conceive reacting circuits having both elastic and inductive couplings and hence to extend the usual equations of alternating-current theory. The extension will probably only prove useful when the coefficient of coupling is other than unity, that is, whenever in the future open condensers are practicable for one reason or another, the triode valve being already a case in point.

Telephone and radio engineers ordinarily say that a condenser offers a path of "low impedance" to the passage of alternating current. This is of course, correct according to the equation

$$I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{p\,C}\right)^2}}$$

. When the frequency is so high that the reactance outweighs the resistance, then as the frequency increases the impedance decreases and the current through the condenser accordingly increases. Thinking in the terminology of elastance, it is plain from equation (**9**) that the effective elastance of a condenser decreases with increasing frequency, and hence the current through the condenser increases. Either statement is correct but there are some advantages in favor of the latter statement; for a condenser is thought of by students, because of the method of approach in alternating-current theory, as a storehouse of potential energy and they know that the greater the capacity of the condenser the more electricity it will hold. Heaviside long ago[11] pointed out that Maxwell's main notion of a dielectric was its ability to yield to elastic displacement. It will probably be of advantage in training future students of alternating-current electricity to stress more than in the past the presentation of the ideas concerning elastance contained in this paper. Professor Karapetoff[12] has shown the usefulness of the idea of elastance when condensers are joined in series and has called attention to the hydraulic analog of the electrostatic circuit. He has called the reciprocal of the farad the "daraf." Professor Kennelly[13] has also found the idea of elastance useful. But neither of these writers mentions the idea of mutual elastance.

Cordial acknowledgment is made of helpful suggestions received in the preparation of this paper from Dr. A. W. Smith of this laboratory and from Dr. J. H. Dellinger of the Bureau of Standards.

10. Electrical Papers, Vol. II, p. 328.

11. Electrical Papers, Vol. II, p. 328.

12. The Electric Circuit, Chapters 6 and 7.

13. *Proc.* Inst. Radio Eng. 4, 1916, p. 47.

NEW BRIDGE ACROSS THE HAWANG-HO ON THE PEKING-HANKOW RAILWAY

The Bureau of Foreign and Domestic Commerce has received a cabelgram from Commercial Attache Julean Arnold, dated at Peking, China, November 27, 1920 which reports that the Ministry of Communications is calling for bids for a new bridge over the Yellow River (Hwang-Ho) on the Peking-Hankow Railway, to replace the present bridge which has been much criticized as not being of sufficient strength to carry properly the motive power that is being used. The present bridge, which is by far the longest one on this line, is 9,875 feet in length, about 11 feet above high water, partly through trusses and partly deck girder construction, all supported on very elaborately placed screw piling. One-half of the superstructure was fabricated in Belgium and the other half in France, and the floor system is all of the stringer type with the openings filled in with metal plates. It was stated that the permissible loading is very little, if any, in excess of "Cooper E-35", and the appearance of the structures would seem to warrant this statement.

It is understood that the specifications for the new bridge will call for a permissible loading of "Cooper E-50." The length of the new bridge will approximate 10,000 feet and will probably cost between $15,000,000 and $20,000,000. The Ministry of Communications reports that the specifications will be ready sometime this week.

The Bureau has cabled for a set of the specifications which, when received, will be available for consultation at its office, Washington, D. C.

ELECTRIC RESISTANCE OF THE HUMAN BODY

During the past few months some measurements have been made by the Bureau of Standards of the electric resistance of the human body. In this work the measurements were made for the first time in such a way as not to include the resistance through the skin where current entered and left the body. By eliminating the large and uncertain resistances through the skin, results were gotten which are more consistent than any previously obtained. These show that the resistance of the same part of the body of different individuals may differ by a ratio of 3 to 2 or even more, the resistance of a person changes from day to day and often by small amounts in an hour, also the resistance depends to some extent upon the position of the body and the extent to which the muscles are relaxed.

There is reason to think that a part of the difference found between different persons and some of the changes observed in the same persons depend upon pathologic conditions. Such measurements may, therefore, be of interest to the pathologist.

A knowledge of the resistance of different parts of the body exclusive of the skin may also be of interest to those concerned with life hazards from high-voltage circuits, since when accidental contact is made to such circuits the skin is burned at the point of contact and therefore largely loses its protecting property.

Operating Performance of Insulators on a 45,000-Volt System

BY H. B. VINCENT

Management Engineer, Day & Zimmermann, Inc.

A description of a form used for collecting data pertaining to the condition of pin-type high-tension insulators removed from service. An analysis of the data obtained from such a report showing the performance of insulators on various lines from 1914 to 1919 inclusive. Percentage of injured and damaged insulators to total installed, and percentage of nature of damage to total failures.

Introduction

As a considerable amount of data has been published in connection with the manufacture, mechanical strength, electrical stresses and laboratory tests of high-tension insulators, it is my purpose to confine mine only to their operating performance.

The following data which refer entirely to pin type insulators have been gathered from actual records kept by a power company operating in the central part of Pennsylvania.

General Description of System

The company transmits and distributes power for mines, industries, street railways, municipal lighting, commercial power and lighting and residences over an area of approximately 350 square miles, serving about 20,000 customers.

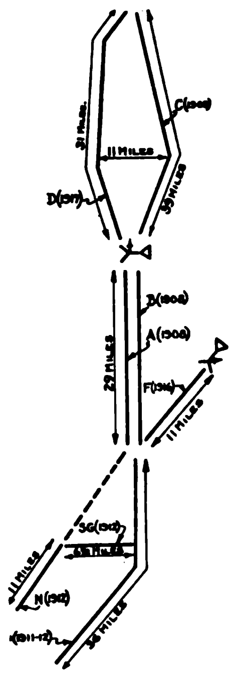

Fig. 1—Diagram of 45,000-Volt System

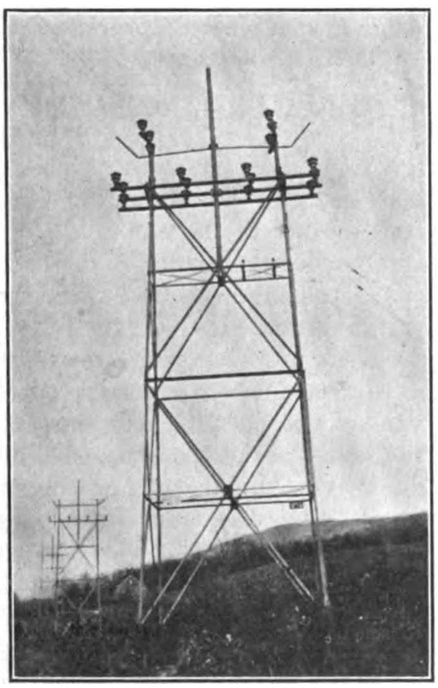

Fig. 2

The power which was originally generated at several separate plants is at present being generated at two plants having a total capacity of 23,500 kv-a. The generating voltage (2200 and 6600 volts) is stepped up to 45,000 volts, which is the major transmission line voltage, the transformers being connected in star with neutral grounded on the high- and delta on the low-tension side.

Fig. 1 shows diagrammatically the 45,000-volt system, the letters designating the various lines being those referred to in the curves shown later.

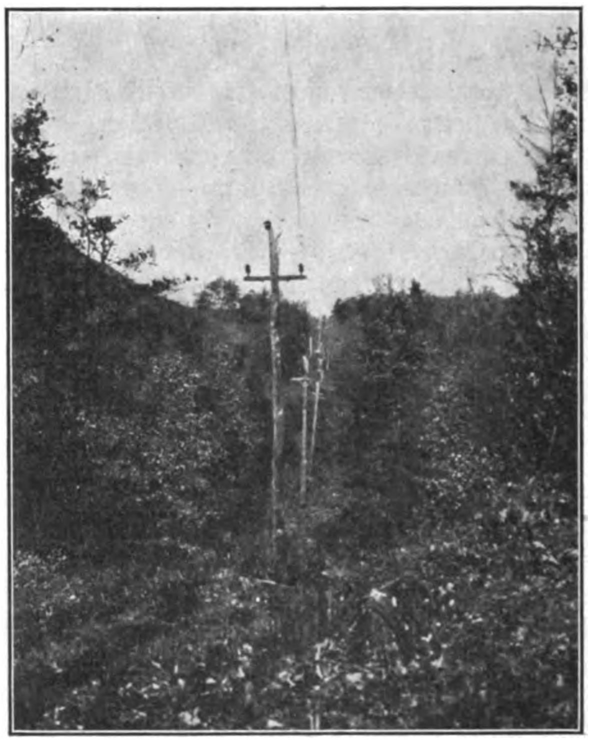

Fig. 3

Types of Construction

The type of construction of the various lines under discussion in general is as follows:

A and *B* is a double-circuit steel tower line, erected in 1908 (Fig. 2).

C is a single-circuit wood pole line with wood cross-arm and steel ridge pin, the latter being grounded through a common bolt with overhead ground support, erected in 1909 (Fig. 3).

D is a single-circuit wood pole line with steel *B-A* arms grounded through the bayonet, erected in 1917 (Fig. 4).

F is a single-circuit steel pole line, erected in 1916 (Fig. 5).

N is a double-circuit steel *A* frame line (with but one circuit installed), erected in 1912 (Fig. 6); the portion shown dotted is similar to *S* line and is

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not included in the following analysis as it was only put into operation recently.

S is a single-circuit wood pole line with wood cross-arms and steel ridge pins ungrounded, erected in 1911-12 (Fig. 7).

S G same as *S* line.

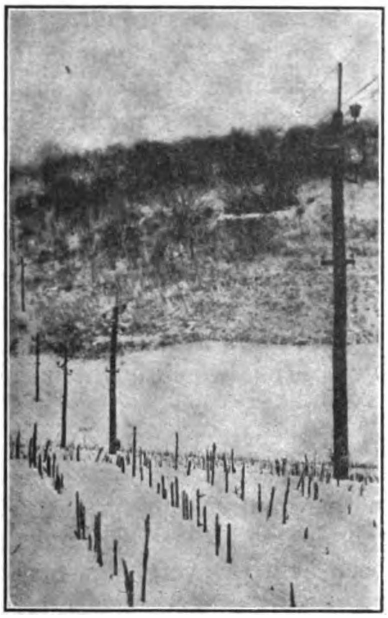

FIG. 4

All the lines are equipped with a quarter-inch Siemans Martin double galvanized stranded overhead ground wire (except *A-B* line which has half-inch), grounded approximately every 800 ft. to a two-inch galvanized iron pipe 6.5 ft. in the ground.

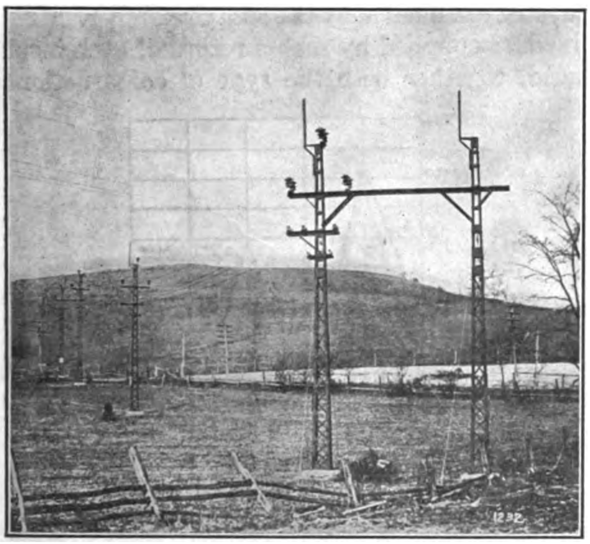

FIG. 5

The normal spans on the steel tower line are 400 feet, on the steel *A* frame, and steel poles 300 feet, and on the wood poles 200 feet (except in particularly severe sleet districts 150 feet).

All pins are metal and in the case of *A-B* lines are cemented directly into the insulators; on *D* line the pins have a separable lead-covered steel thimble which eliminates cementing; on the balance of the lines the

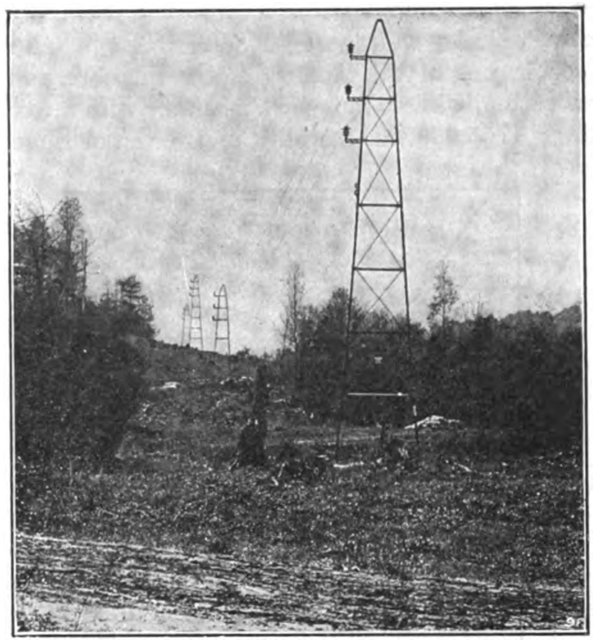

FIG. 6

pins screw into a metal thimble cemented into the insulator.

Both aluminum and copper stranded cables are used for the conductors.

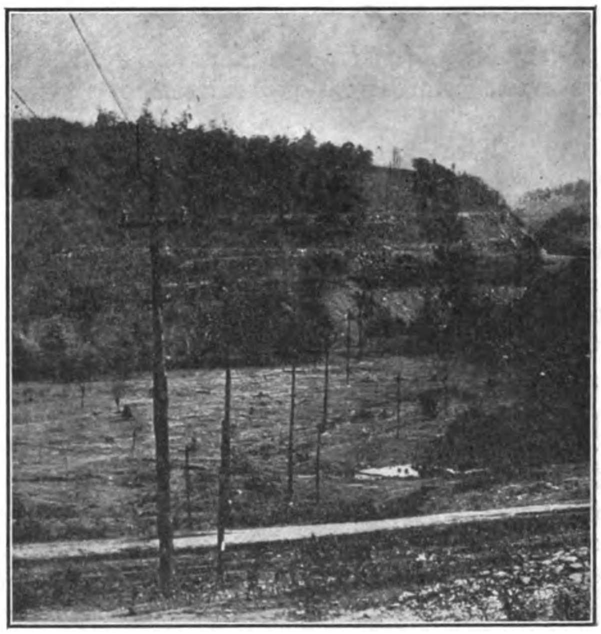

FIG. 7

NATURE OF TOPOGRAPHY

The majority of the lines traverse very mountainous country and are subject to severe lightning, sleet and wind storms, although there are sections which follow valleys or lowlands for some considerable distance.

The maximum elevation is about 2400 feet and minimum about 550 feet.

TYPE OF INSULATORS

The insulators installed on the first three circuits erected (*A*, *B* and *C*), were three-part with a rated line or working voltage of 50,000; those installed on the crossarms of the balance of the lines were of the same rating, while a four-part insulator with a working voltage of 60,000 was installed on the top or ridge pin.

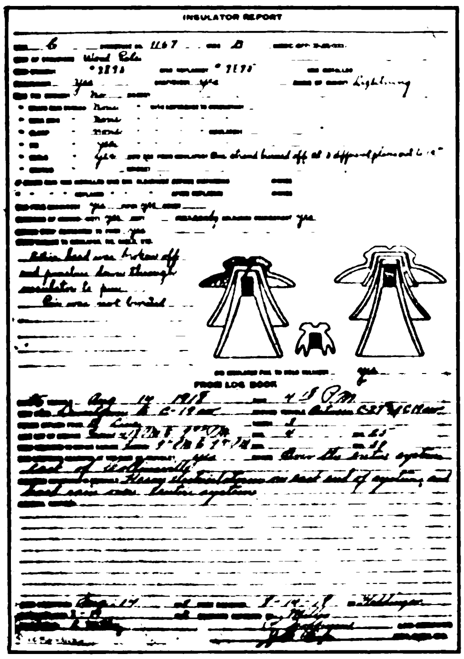

FIG. 8

With very few exceptions all strains and dead ends are made on two or three pin-type insulators.

TIES, SERVING AND SHIELDS

Both tie clamps and regular ties have been used, though the present practise is to use only the latter. Special serving and shields have only been used on crossings of other facilities, and then only when the latter's specifications required them.

No metal caps have been used except on line or disconnecting switches.

RELAY PROTECTION

The original lines were installed with overload inverse-time element relays, but as the size of the system grew, through the addition of lines, difficulty was experienced in obtaining proper selective action in case of short circuits; this was overcome by replacing the inverse-time element relays by definite and inverse-definite time limit relays.

PATROL TESTING

No special means are employed for detecting faulty insulators in service; a regular weekly patrol is maintained, augmented by special patrols following severe storms or where momentary interruptions would indicate some unknown trouble.

SPECIAL TESTING

The company has installed a high-frequency testing outfit which is used for comparative tests.

LIGHTNING STORMS

Inasmuch as lightning plays such an important role in high-tension operation a record has been kept of the number of storms occurring at different points on the system, which allows of at least a relative comparison between yearly damage and quantity of each season's storms.

Since such a record has been kept of the lightning storms an effort has been made to determine if they were more severe or frequent in any particular location of the system with consequent greater insulator damage, but nothing definite has been brought out by the analysis.

RECORDS

No detail records were kept of the performance of insulators on the transmission system prior to 1914. However, beginning with that year, and since, a detail record has been kept of every high-tension insulator removed from the lines together with a record of the style and make of the one replaced by it. The form of record used (Fig. 8) is probably similar to that used by other operating companies. That portion of the form dealing with physical conditions, *i. e.*, the structure, number, style and location of insulator, evidence of burns and actual conditions of insulator as found, is filled in by the repairman or lineman who changed the insulator. The operating data, *i. e.*, when the line failed, etc., are filled in by the load dispatcher.

The data supplied by such a record of each insulator replaced, together with the type of construction and

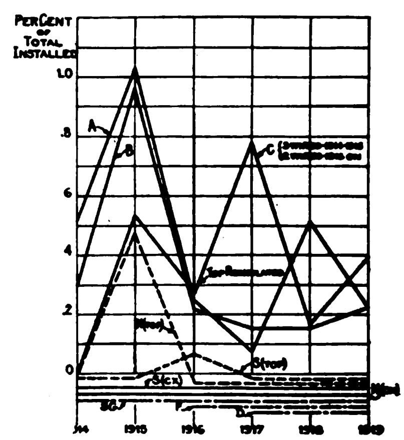

FIG. 9—YEARLY PER CENT OF INSULATORS INJURED BY CRACKS—BY LINES

date when the line was put into operation, permit an analysis to be made at any time of its performance with respect to style and age, and should show if a particular weakness is developing.

Classification of Insulator Defects

For the purpose of the following analysis the insulator defects have been subdivided as follows:

a. Cracks, *i. e.*, those which have been removed from the line due to mechanical defects, which defects were found by special inspection or by excessive static conditions being noted by the patrolman.

b. Injured, *i. e.*, those which held voltage but which were considered a menace to operation, although such an injury might have been caused by a rifle shot or stone; only those showing signs of a flash-over have been considered.

c. Damaged, *i. e.*, those which failed to hold voltage, such damage being a flash-over, a vertical or a horizontal puncture.

Analysis of Insulator Reports

a. Cracked Insulators. In Fig. 9 is shown the yearly percentage of insulators injured by cracks by lines, from which it will be seen that excepting the very small per cent on the top wire of S line, the defects

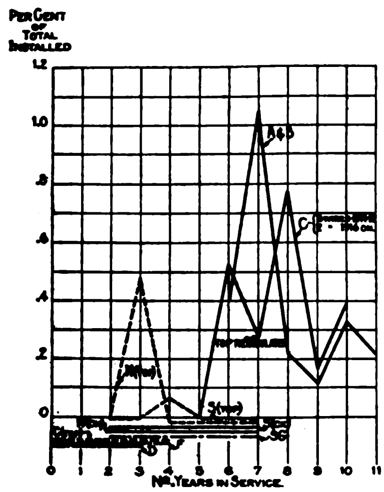

Fig. 10—Per Cent Insulators Injured by Cracks with Respect to Years of Service—By Lines

have been occurring on A, B and C lines. This condition was discovered primarily by an investigation of the increase of insulators damaged in 1915 over 1914, a mechanical inspection being made after the 1915 lightning season.

As the majority of failures on C line were occurring on the ridge pin (which, as previously stated, was grounded) it was decided to reinsulate this top wire. This was done before the 1916 lightning season, which is reflected in the decrease in damaged insulators on that line as seen by a later chart. In reinsulating the top wire a four-part insulator with a working voltage of 60,000 was used.

It will be noted that there was a larger percentage on A and B lines; these lines were not reinsulated at that time due to the fact that they formed a duplicate circuit, but due to the increasing number of failures in the past two years A line will be entirely reinsulated before the coming lightning season.

In the case of the latter lines all three wires showed about the same per cent of injured insulators.

The question is often asked, "What is the life of an insulator?" This can hardly be answered, but from the records of the particular system in question we have decided that in the case of A, B and C lines the service being obtained by these insulators warrants their removal.

In Fig. 10 we have shown the percentage of insulators injured by cracks with respect to years of service by lines, from which it will be noted that, in the case of A, B and C lines, trouble started after five or six years. Although some of the other lines show no signs of cracking, these insulators are of a later design.

The cracking referred to in almost all cases has occurred in the top skirt, causing the head to shear off in the plane of the tie wire groove, due we believe to unequal expansion and contraction between the porcelain and cement, caused by aging of the latter material.

Although we have not experienced any trouble with the insulators on the 45,000-volt system, which might be attributed to cementing the pin to the insulator, we have had this trouble with insulators used on a lower voltage line, hence our present practise is to use a lead thread or thimble in place of cement and metal thimble.

b. Injured Insulators. The performance of the insulators on the various lines with respect to injury due to flash-over is shown in Table I.

TABLE I

Percentage of (total) Insulators Injured by Flash-over—By Lines

Lines	1914	1915	1916	1917	1918	1919
A & B	0.15	0.33	0.29	0.18	0.91	0.69
C	0	0.08	0.03	0	0.10	0.03
D				0	0	0.09
F			0	0.32	0.11	0.11
N	0.16	0.47	0	0	0.16	0
S	0	0	0.05	0.09	0.16	0.02
SG	0	0.13	0	0	0.13	0

As far as the records show these flash-overs were caused by lightning.

A detailed analysis shows double the percentage of flash-over of the top wire insulator over the cross-arm or bottom insulators on S and F lines since 1914. However, if all of the lines are considered the percentage is about equal.

The records further show that the percentage since 1914 on the grounded pins is 0.95 against 0.29 on the ungrounded pins.

c. Damaged Insulators. Fig. 11 shows the yearly percentage of insulators damaged by lines. A decrease in failures is noted on C line as a result of the reinsulation of the top wire in 1916, but failures have increased since 1917. Although the same type of

insulator as used on the top wires of *F*, *N* and *S* lines (which shows practically no failures) was used to reinsulate the top of *C* line, it will be noted that an increasing number of failures are occurring on the reinsulated line, the cause for which has not yet been determined.

The relatively large number of failures on *A* and *B* lines is no doubt being caused by the cracking of the top skirt previously referred to.

The failures occurring on the various lines with respect to years of service are shown in Fig. 12.

Fig. 13 shows the yearly percentage of insulators damaged, by styles, and also the number of days lightning occurred.

A detailed analysis showing the failures segregated between the top wire and crossarm in percentage of total number of each installed by styles is shown in Table II.

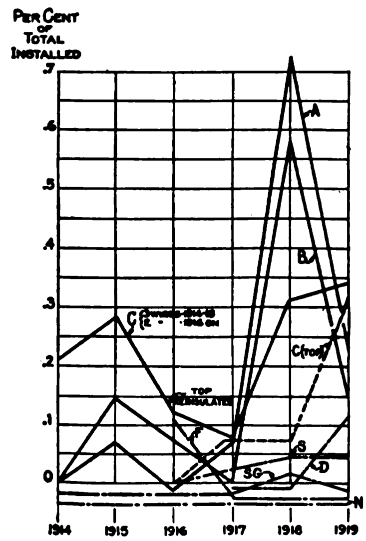

FIG 11—YEARLY PER CENT OF INSULATORS DAMAGED—BY LINES

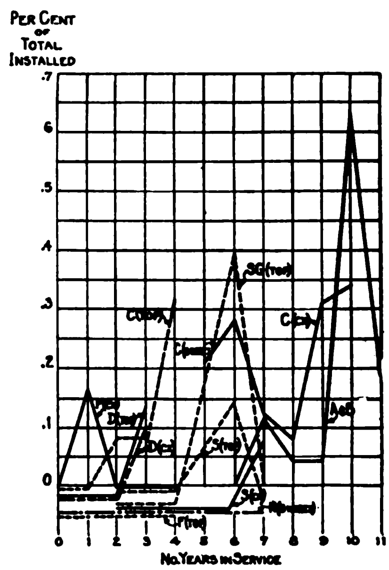

FIG. 12—PER CENT OF INSULATORS DAMAGED WITH RESPECT TO YEARS OF SERVICE—BY LINES

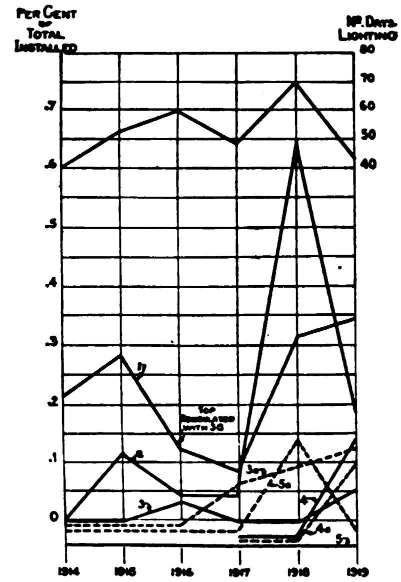

FIG. 13—PER CENT OF INSULATORS DAMAGED BY STYLES, AND NUMBER DAYS LIGHTNING OCCURRED

TABLE II
Percentage of (total) Insulators Damaged—By Styles

No. Parts	Styles	1914	1915	1916	1918	1919	1919
Crossarm Wires							
3	1	0.08	0.08	0.12	0.08	0.31	0.34
3	2	0	0.03	0.02	0	0.60	0.80
3	3	0	0	0.03	0	0	0.05
3	4				0	0	0.13
3	5	0	0	0	0	0	0
Top Wires							
3	1	0.47	0.70				
3	2	0	0.11	0	0.11	0.77	0.22
4	3a	0	0	0	0.06	0.09	0.12
4	4a				0	0	0.09
	5a	0	0	0	0	0.13	0
Total Crossarm		0.02	0.05	0.06	0.02	0.17	0.15
Total Top		0.15	0.24	0	0.05	0.20	0.13

A further segregation of the damaged insulators into nature of damage shows the following for the total period of time (1914 to 1919 inclusive) the records have been kept:

Vertical puncture.........27.4 per cent
Horizontal puncture.......39.0 per cent
Flash-over...............33.6 per cent

CONCLUSIONS

The effect of the performance of the insulators on interruptions or continuity of service has not been touched upon, but since the records have been kept analyses have been made in particular cases.

To make such an analysis each of the individual lines would have to be treated separately and jointly, depending on operating conditions at the time of the trouble; further, the duration of the interruptions varies, depending on the location of the faulty insulators and the accessibility of that section of the line.

In the case of the disk-type insulators, quite a few operating companies are keeping complete records of their performance, and from the nature of the insulator are able to make periodic tests of each unit, and by providing a high factor of insulation can replace weak or defective units to reduce the probability of complete failure.

From a study of the high-voltage pin-type insulators now on the market it would seem that the manufacturers are endeavoring to overcome the cracking of the parts, but the operating companies will have to do their part by supplying reliable data in connection with the actual performance under operating conditions.

Hence my thought has been simply to present a method for the recording of insulator performance, showing how such a record enables one to know what service the insulators are giving, and what one may expect provided the records have been kept over a sufficient period of time.

The Application of Electric Power to the Rubber Industry

BY THE SUB-COMMITTEE OF THE INDUSTRIAL AND DOMESTIC POWER COMMITTEE ON THE RUBBER INDUSTRY*

INTRODUCTION

HISTORY shows that something was known of rubber to civilization as early as 1525. In 1736 a French expedition of scientists, who were sent to South America for geographical research, sent back samples of rubber, and reported that it was obtained from a certain tree which the natives called *hevea*. Even at this early date they further reported that the natives were using this material to waterproof various articles of wearing apparel. This material was soon used in England for removing pencil marks, and hence has been termed *rubber*.

About the beginning of the nineteenth century Samuel Peal and Charles Macintosh, both of England, in turn, proposed the use of rubber in solution for impregnating fabric. The former attempted to make air-cushioned beds, and the latter made waterproofed rain coats. The attempt of Macintosh in 1820 marks the first important step toward the application of rubber to the needs of civilization.

It was not however until Charles Goodyear in 1839 made his almost accidental discovery of vulcanization, that rubber promised to become a material of a very important and far-reaching industry. The facts that the addition of sulphur to crude rubber, and as later learned, adding sulphur with other compounding ingredients to rubber, and subjecting the mixture to heat, so that the mass became *cured*, making further changes of its physical properties practically unchangeable within reasonable ranges of temperature; and further that the compounding materials could be adapted, both in kind, and in amount, to produce a rubber of widely varying physical characteristics; all laid the foundation for an industry which today is manufacturing articles of universal use and application, and, according to Government statistics, stands at the head of the list of "Individual Large Users of Electric Power."

Crude Rubber is obtained from certain species of tropical and sub-tropical trees, shrubs, vines, and the roots of certain plants. In the case of trees and some vines it is coagulated from the milk-like fluid known as latex which exudes from cuts or sores in the bark, while rubber exists in some vines and most shrubs in a solid form incorporated with the woody fiber. In the case of the latter the rubber is obtained by complete maceration of the entire shrub by the means of suitable pulp grinding machinery assisted by the use of water, which carries off the pulp and bark while the rubber is reduced to an agglomerate mass, and passes out of a suitable opening provided in the machine.

The various grades and brands of rubber are usually known by the name of the geographical locations in which they are obtained. This nomenclature is especially common among practical rubber men. It is now true that there is a tendency, especially among engineers and chemists, to speak of rubber according to a botanical or other scientific classification. The finest quality of rubber is obtained from South America, while grades of less value are obtained from Central America, and Mexico, and some of the shrub variety from Texas. Large quantities of rubber with some very good grades are secured from the tropical, and sub-tropical regions of Africa, Asia and Australia.

Milling and Washing of a thorough character of all grades of rubber are essential. At the plantations it is either run through a sheeting mill, or through a creping mill, while in the case of those kinds shipped without receiving either of the above operations, it is thoroughly mechanically disintegrated in a washing mill at the various rubber factories.

Summary of Committee Activity

United States Government statistics show the rubber industry to be the largest individual user of electric power.

How this large amount of electric power is applied, is the duty of this committee to show. We hope that our work may assist the engineer in electric power application problems, to render this large power more efficient, and thus help assist humanity in its efforts toward conservation.

This committee has planned its work to include a number of divisions, each division being sub-divided, making it more easy to digest.

POWER CONSUMPTION

1. *Basic Machinery Applications*. The power demands in this division are for electrical units of relatively large horse power and constant speed. These general milling operations embrace the following machines:

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*WILLIAM E. DATE, Chairman, Cutler-Hammer Mfg. Co., New York, N. Y.

MARTIN BERTHOLD, Imperial Electric Co., Akron, O.

BYRON T. MOTTINGER, Quaker City Rubber Co., Philadelphia

CHARLES A. RICE, Republic Rubber Co., Youngstown, O.

HENRY F. SCHIPPEL, Aimes, Holden, McCready, Ltd., Montreal, Canada.

a. Washers.
b. Crackers.
c. Mixers.
d. Batch mixers.
e. Safety stops.

2. *Intermediate Process Applications.* The power demand in this division is met as a rule by special applications of moderate-size electrical units, adjustable speed.

Semi-Finishing Machines
Calenders and Calender Drives.
a. Individual drives.
b. Conveyers.
c. Synchronous control of calenders, and of calenders and conveyers.

3. *Finishing Process Applications.* The power demand in this division is for electrical units of relatively small capacity. Constant speed as a rule. Some machines require adjustable speed, continuous running. Others are intermittent, frequent "start" and "stop," and some types must be equipped for frequent "reversals."

Finishing Machinery.
a. Fabric bias cutter.
b. Tire building machinery.
c. Tubing machines.
d. Insulating machines.
e. Hose loom.
f. Hose braiding machines.
g. Hose wrapping machines.
h. Hose stripping machines.
i. Hose building machines.
j. Rubber shoe machinery.
k. Rubber glove machinery.
l. Hard rubber machinery.
m. Mechanical rubber goods machinery.

4. *Electric Heating Applications.* Only a limited amount of electric heating has been applied to the rubber industry. Possible applications are being investigated.

5. *Contributory Problems and Applications.*
Power Supply. Transmission.
a. Power and lighting switchboards.
b. Transformation of alternating current to direct current for adjustable motor speed requirements.
c. Air compressors.
d. Hydraulic pumps.
e. Elevators and hoists.
f. Floor and street trucks.

Power Economy

A study of the subject in the abstract, should show the engineer where, by making a power application of a certain type in one division, he may lessen the losses in another division.

A study should be made of each concrete problem, selecting units of relatively low initial torque but high all day efficiency where high initial torque is not required; and selecting units of relatively high initial torque, and of a continuous load capacity suitable for the work, so that power efficiency can be increased. This conclusion is reached without overlooking the facts, that much of the rubber mill machinery is subject to high peak loads, and that continuity of operation is of importance to production.

It is not the intent of this paper to reflect in any manner against the progress that has been made, but to suggest that possibly greater care should be taken in selecting electrical equipment of the most suitable type and size for each application so that increased efficiency will obtain.

Protection to Operatives

Owing to the tenacious characteristic of rubber in its plastic state, a hazard to the mill operators is at all times present. Hence the need of safety protection is imperative.

Conclusions

a. Possibilities of electric power.
b. Application of 40-degree and 50-degree motors.
c. Steam *vs.* electrically heated drying ovens, (250 deg. fahr.)
d. Steam *vs.* electric heat treatment of vegetable compounds. (250 deg. fahr.).

BASIC OPERATIONS

General Considerations

Processes

The general milling or basic operations obtain in every class of manufacture of rubber articles.

It is in this general division that the crude rubber is treated, compounded and probably colored, to produce the mixture required for the specific need. The per cent of pure rubber in different articles is a large variable, being high in one class, and low in another. In general milling operations, there are many variables that affect the power requirement. Examples: Source of supply of crude rubber. Working temperature of rolls. Pressure on rolls. Grade of compound or mixture.

General milling operations include the "washing," "cracking," "mixing," and finally "batch warming" ready for the calenders.

Motor Selection

Gearless Drive. The earlier type of motor drive involved a moderate-speed motor, geared to the mill shaft through spur gear reduction gears, the gear ratio employed, as a rule, being approximately 1 to 6, to provide a mill-line shaft speed of approximately 90 rev. per min. Of recent years, the herringbone gear became popular for rubber mill machinery, with the result that a large proportion of installations made during the past few years have been equipped with herringbone gears.

The prevalent tendency is an endeavor to eliminate the gear reduction, and connect the motor shaft directly to the mill-line shaft. This requires a very low-speed motor, and is impracticable with large size induction motors, either of the squirrel-cage-rotor, or of the wound-rotor type. The synchronous motor however is readily adaptable to this low speed and provides the advantages of high power factor, which is of large significance in view of the widely varying loads encountered in milling, in addition to the elimination of costly, noisy gearing. The elimination of gear maintenance is a large factor.

The first gearless installations made, of which this committee has record, are at the plant of the Republic Tire and Rubber Company, Youngstown, O. These were installed many years ago, and the reports obtained by this committee indicate that the company feels after years of operation that its judgment was sound in their selection.

The point we wish to bring out, however, is the possibilities of the gearless drive. This question settled it simply becomes a question then, of selecting the suitable modern type of low-speed motor.

Voltage. The majority of milling operations require motors of large capacity and of constant-speed characteristics. That these motors may advantageously be of high voltage, direct from service lines, eliminating step-down transformers with their additional losses, is a factor worthy of consideration in power application.

Motor Size. Several factors are included in the selection of motor size and some of them to our minds improperly. To clearly stress these last, there immediately follows a discussion of *horse power rating* and *power factor and efficiency at full rated load,* following which will be indicated with discussion the two factors *torque* and *thermal capacity* that alone count.

Horse power rating means simply that a motor will, when developing a defined rated torque (known as full-load rated torque), at a defined rate of speed (known as full-load rated speed), have a temperature rise, not in excess of a defined value.

This may be amplified by time limitation, such as 30-minute rating; one-hour rating; two-hour rating; but it assumes a constant load.

In milling operations does this condition exist?

The load, that obtains in milling operations, has a possible variation from a minimum of friction load, with all mills empty, up to a possible maximum of simultaneous loading of all mills on the line.

With an individual drive (one mill only for each motor), both the minimum, and maximum condition will obtain. With two mills the same result is probable. With three mills to a drive, it is probable at infrequent intervals. With increasing number of mills to a drive the probability of obtaining the possible maximum peak load decreases. With five mills the probability is that the maximum load at any one time will be 75 per cent of the possible maximum. With eight mills to a drive the probable maximum load will be 50 per cent of the possible maximum. The greater the number of mills to the line, the more closely is a constant-load condition approached.

This is not intended as a justification of placing all mills in a plant on one mill line. The number of mills, and sizes of mills to a mill line are governed by local conditions over which the electrical engineer has no control.

The purpose is to emphasize the conditions which confront us in motor size selection.

We want to bring out clearly:

1. That greater number of mills to the mill-line drive does not increase maximum torque requirement proportionately.

2. That greater number of mills to the mill-line drive does eliminate to some extent the depth of the valleys in the load curve, and that the peak loads do not increase proportionately to the number of mills.

The two important factors are: Torque, and thermal capacity.

a. Select a motor having a pull-out torque capacity in excess of the maximum torque requirements; this motor to have a thermal capacity sufficient to carry the mean load continuously without heating beyond prescribed temperature rise limit.

b. This motor should have a high mean power factor carrying the mean load determined for the thermal capacity selection.

c. This motor should have a high mean efficiency, carrying the mean load determined for the thermal capacity selection.

d. This motor should have high speed regulation characteristics when carrying the loads that obtain when developing any torque, between 20 per cent of the maximum torque pull-out value, and maximum torque pull-out value.

e. This motor should be mechanically constructed so as to withstand the load shocks imposed by the frequent peak loads that obtain. (Caution should be exercised to obtain ample size of shaft, bearings, and rotor structure).

A motor selected on this basis would not be over-size. Over-size motors increase investment, have a lower combined mean power factor efficiency, and are not justified for economical production.

If motors have poor speed regulation characteristics, under the varying loads that obtain, production is lessened. One example of motor selection on this basis can be cited, and there are probably many others.

In 1915 an installation of 40 mixers was contemplated for low-grade compound for one plant. The plan was to operate in groups of two, with a total of 20 drives. One machinery manufacturer offered 100-h. p. motors. Another 75-h. p. The engineer, considering the nature of the compound, was satisfied with

neither. The order was placed for the mills, and the motor size selection withheld 30 days, during which time a continuous test was made with a graphic meter (24 hours per day, three shifts of workmen), on the same size of mills and the same mixture of compound.

The result, was the selection of motors nominally rated at 50 h. p. but which had ample pull-out torque capacity for the peak loads, and ample thermal capacity rating for the mean load. These motors have now been in successful operation for over three years, and over a considerable period of time were operated 24 hours per day.

In 1919 eight similar drives were added.

In another plant is a four-mill drive fitted with a 400-h. p. nominal rating motor. A test with all mills operating showed a maximum load of 300 h. p. After several hours of test showing a load fluctuating between 50 h. p. and 300 h. p., an appeal was made to the superintendent to provide conditions that would give a maximum load condition.

The superintendent had a special grade of stock trucked in for the test. He instructed all workmen to handle the work in a manner to provide the maximum load possible, and the highest load peak obtained was 405 h. p.

These examples are not offered as a plea for small or under-size motors, but simply to emphasize against the waste of using over-size motors.

Motor Controller. The motor controller recommended by this committee for general milling work would comply with the following specifications:

a. Controller to be of a totally enclosed type.

b. Controller to be manually operated, from a lever or external mechanism.

c. Controller to be fitted with inverse-time-limit overload protection.

d. Controller to be fitted with low-voltage protection.

e. Controller primary switching mechanism to be of a type suitable to the voltage of the system. For 550 volts or less, air-break, fully enclosed, primary switching mechanism to be preferred. For 2200 volts or higher, the switching mechanism of the primary switch to be oil-immersed.

f. The resistor, if required, to be of cast metal grids, 30-second duty rating, open structure, for mounting separate from the controller.

g. The controller to be interlocked with the safety stop mechanism so that the motor cannot be started with any of the safety stop devices in the "safe" position.

Washers

Crude Rubber to Pure Rubber

Crude rubber, whether *wild*, or *plantation*, is a dirty brown mass. It may be in the form of large balls, small balls, or rectangular chunks. In any event it is a conglomeration of dirty gum, sand, stones, and sticks. It may be "smoky," or it may not be.

It must not only be "washed," but it must be disintegrated, and the rubber particles separated from all foreign substance. When thoroughly washed, disintegrated and separated, the color of the resultant granule is that of rich cream. Thus, the change from *crude* rubber to *pure* rubber. The quality of the pure rubber is dependent largely on the geographical source of supply of the crude rubber.

Continuation of the washing produces coagulation, and results in rough uneven crepe-like sheets, of about the size of a page of your daily newspaper.

If the *sheeting* term is disregarded and the mind is placed on a granular substance, such as granulated sugar, the next phase of procedure will be more readily understood. We must now change the "granulated sugar" into "taffy."

The next operation causes coalescence. The granules are broken down, and fused, resulting in heavy sheets of pure gum approximately ⅜ inch in thickness. Although water is not used in this phase of the process, we class it with washing, in that the accounting systems of many plants use the same classification.

The crude rubber is "accounted out" to the washer room as crude rubber, and is "accounted back" to the store room from the breaking-down mills, as the resultant product of these various procedures.

Motor Selection

Disintegration. This process involves machines, known as "washers" in some plants, and as "crackers" in others.

The rolls on these machines are fluted spirally. Both rolls are fluted in the same direction, but are rotated in opposite directions. The speed of one roll is higher than the other. The ratio of friction is unusually high, as a rule. This ratio is as high on many machines as 1 to 1⅜. The distance between the rolls may be ⅜ inch or greater.

Analysis of this type of machine and the material it must handle shows the following load characteristics; all of which obtain simultaneously, and all of which are in the nature of suddenly applied loads:

a. A relatively short heavy chunk of cold crude rubber forced into the V between the rolls, until the rolls grip and wedge it through, causes a heavy suddenly applied load, with resultant shock.

b. The spirally fluted rolls, one of higher peripheral speed than the other, cause a combination of dragging in, wedging, crushing, cutting and tearing apart action producing a heavy, suddenly applied load, with resultant shock.

c. The high ratio of friction, the peripheral speed of one roll so much greater than the other, is a large factor in itself toward producing a heavy, suddenly applied load with the resultant shock.

d. The wide separation between rolls is another large factor toward producing a heavy, suddenly applied load with resultant shock.

All of the foregoing indicate that every characteristic produces heavy suddenly applied loads with resultant shock. Aside from the mechanical ability of the motor to meet high shock demands there must be that ability in the motor to pull through the peak. There must be the required turning ability in the motor to absorb the resultant shocks. Turning capacity is the essential feature for peak loads.

There is one redeeming feature to washer work. The peak loads are of short duration. The peak load obtains only when the heavy, cold chunks are passed through. The actual time of passing a chunk through the washer, assuming good speed regulation, would be from $^2/_3$ of a second, to $1\frac{1}{2}$ seconds. It is possible to have this condition repeated in rapid succession. This could result from feeding chunks to the washer in rapid succession.

Nevertheless, the peaks are of short time duration and kinetic energy of rotation should be included in calculations determining motor size selection.

The turning ability then can be the result of two factors. *Inertia* and *torque*. If the inertia is relatively high, the torque may be proportionately decreased, so that the sum of the two is of ample capacity to carry any reasonable peak load.

It is fallacy to permit mill operators to force the mills to do unreasonable work, and it is not good practise to equip a mill or mill line with motors of a capacity largely in excess of that of the mechanical equipment. The mechanical equipment is designed to absorb all reasonable shocks. The motor capacity should be proportionate and the motor should have suitable protective devices to protect it in event of attempted abuse by operators. When this protective device stops the mill line, there should be no attempt made to force the motor and mill line to do the unreasonable, that which it is not designed to do. The jammed material should be backed out of the mills or the pressure on the rolls released, thereby relieving the equipment of unreasonable abuse.

If this cooperation obtains between the production department and the engineer there will be no temptation to equip with motors largely in excess of reasonable requirements or in excess of the capacity of the mechanical equipment.

A suggestion that is not irrevelant at this stage, would be the installation of a visible signal on each washer mill. This signal would indicate to the operator at any time that the reasonable load point had been attained. The operator on any one mill would know that the mill line was up to capacity. Each would know at once whether his individual mill were overworked; if not, he would feed with reason; if so, he would delay further feeding. Non-attention to the signal and further forcing and abuse would cause a shut-down on the mill line.

With a signal system of this nature the motor size selection may be on a basis of reasonable peak load, with assurance that not only the motor but the entire mechanical equipment as well, will suffer little abuse.

Then,—(1) With a true knowledge of the nature of the material to be washed, (2) With a true analysis of the characteristics of the machine, (3) With a thorough understanding of what is a reasonable peak load, the problem as far as turning capacity is concerned, simply becomes one of selecting that type of motor which is best suited to the plant conditions and to the mechanical structure of the drives, that is, whether geared or gearless.

Due consideration must be given to a washer line where a number of washers are involved. Also to a mill line that may incorporate sheeting and breaking-down rolls.

The law of average will obtain on a mill line driving a number of washers, or a mill line driving a number of mills of different types.

On washer mill lines the engineer may make a formula along the following lines, such to be based on tests in his own plant under the class of material conditions and the working conditions that obtain there. The formula here presented represents average plant conditions, as owing to the many variables it is impossible to offer a formula that is applicable to all.

Assume one washer on a given stock, reaonable peak load to equal 100 per cent.

Let N = number of washers
K = a constant

TABLE OF CONSTANTS

No. of Washers	K equals
1	1.00
2	1.00
3	0.85
4	0.82
5	0.80
6	0.72
7	0.67
8	0.62

The formula then would become 100 per cent $X\ N\ X\ K$ = peak load capacity required for a given number of washers in per cent of the peak load capacity required by one mill.

Assume a given size of washer requires a peak load capacity equal to 132 actual h.p., then four such mills would on this basis indicate a peak load requirement of 432.96 h. p.

The constants given here are average, and are conservative considering the test data available. They should not be considered, however, as recommended working constants. Each problem should be studied from its own or similar plant conditions.

It is important however to bear in mind, that calculations should be based on peak load capacity of the motor, and not on the nominal h. p. rating. This is of especial importance if applied to synchronous motors, as there is a wide difference between the maximum torque capacity of the synchronous motor and the in-

duction motor. It is also important as there is frequently an appreciable difference between the maximum torque capacity of different induction motors of the same nominal h. p. rating.

The important point is the selection of a motor of sufficient turning capacity, when operating at its rated speed, to carry through those peak loads that have been determined as reasonable. Second, to signal the operators when they have attained that peak load, that has been determined as reasonable. Third, to shut the line down, should the peak assume an injurious proportion.

The following abridged list is given of some existing installations which were selected at random, and not purposely to show the wide divergency in motor selection that it is possible to show. They are included to emphasize the fact that a definite basis of selection cannot be given. At least not until all available data, and all data that it may be possible to secure, have been brought together under one head, thoroughly analyzed and tabulated.

SOME TYPICAL WASHER INSTALLATIONS

Face of Mill	Nominal H. P. Rating of Motor	Nominal H. P. Per Inch of Face
30 inch	50	1.66
36 "	40	1.1
4—48 "	250	1.3
4—40 "	150	0.94
3—60 and 1—36 inch	250	1.15

Any engineer would be justified in remarking the apparent inconsistency, although all the mills may be consistently equipped. The table does not indicate diameter of rolls, nor grade of material. The data do not indicate the friction ratio, nor the distance between rolls.

Can we have a rule, applying correctly, based on the length in inches of the face of the roll? Can we have a rule, applying correctly, based on the nominal h. p. rating of a motor?

This committee believes that neither question can be answered in the affirmative. Such rules must be general or be so liberal that to equip with motors safely those mills that do the hardest work, all other drives will be inefficiently over-supplied with power.

The committee believes that such rules have not been followed in general, as data it has indicate some mills equipped with as low as 0.695 nominal rated h. p. per inch of roll face, and other similar mills with as high as 1.39 nominal rated h. p. per inch of roll face.

The committee is confident that many engineers directly associated with the rubber industry have studied the basic problem and that they personally were responsible for the correct motor equipment of their mill lines.

All of the foregoing concentrate on that one phase of motor selection, that phase which determines the peak load capacity which must obtain in the motor. If this were the only issue then the problem would be solved by simply selecting a motor able to meet this demand. But following the process of disintegrating further shows clearly the other factors that must be considered.

That portion of the initial operations which produces high peak loads, is a part of the initial operation load cycle. For that brief period while the "chunk" is passing through, the peak load obtains. During the remainder of the cycle the machine is empty. The load valley is low. In the initial operation the load varies from a minimum of friction load only to the maximum peak load. The thermal capacity requirement of the motor is correspondingly reduced.

Following the disintegrating process further, we find that after the initial operation, of passing through the crude dirty chunks, the now partially disintegrated material is passed through the mill a number of times, this being continued until complete disintegration has been accomplished. This portion of the process must be considered in conjunction with the initial portion of the process in order to determine the mean load value.

The maximum peak load that obtains during the process following the initial process, is approximately 50 per cent of the maximum peak load of the initial process, so if the motor has peak load capacity to handle the initial process peak load we need have no further concern on peak load capacity. But this lower peak load that obtains after the initial process, is a factor in determining the mean load; in determining the thermal capacity requirement of the motor; in determining the basis for efficiency and power factor selection.

An analysis of the actual conditions will show:

1. Abnormally high peak loads, few in number and each of short-time period.
2. Abnormally light-load short-time periods.
3. A mean load that does not exceed 30 per cent of the probable maximum peak load.

(Note) Please bear in mind that this suggested analysis is to be on a basis of one washer room line and do not confuse it with the load factor of an entire plant.

The committee considers this a problem. Is it possible to equip this disintegrating mill line with motors without sacrificing efficiency and power factor and at the same time maintain that large important factor of electric application, namely, flexibility of power application?

It is reported that in tire mills, one horse power is required per tire per day. If this is correct, is it a high tax to place upon the output? If so, can it be decreased?

The extreme flexibility of electric power application has been probably the largest factor in popularizing its use in the rubber industry. Has the flexibility

been extended beyond a reasonable and efficient point? Have mill lines been split up into such a large number of units for production efficiency at a sacrifice of electrical efficiency, that in some instances may not be warranted? This committee does not imply in any manner that such is true. It simply asks the question.

The power requirement as indicated by reported connected load statistics is stupendous. It is so prodigious, that we feel that only by close cooperation between the electrical engineer and the plant production department, weighing together the advantages and disadvantages of segregating here or grouping there, can electrical efficiencies obtain. This must be evident to all.

Where a production efficiency is to be gained at a sacrifice of power efficiency and where this anticipated gain in production efficiency would be less than the resultant losses in power, so that the net result would be a loss, the fact should be recognized and a compromise made that will permit of production on a reasonably efficient basis, with the power application on a similarly efficient basis with a net result of gain.

Where a production efficiency is to be gained at a sacrifice of power efficiency, and where the anticipated gain in production efficiency would be in excess of the power losses, there will as a rule be no question of compromise involved. The net result would be gain, and it is obvious that the engineer would cooperate fully with the production department.

In motor selection the foregoing should be determined definitely so that the engineer may know the operating requirements of that specific department of that specific plant. That point being determined he then has at least two possible factors that will help him to select motor equipment efficiently; these factors are as follows:

1. The adaptability of a signal system to guard against abnormal peak loads. The adaptability of a protective device to stop the mills should the operator disregard the signal.

2. The practicability of placing a number of washers (disintegrating process mills) all on one line, and obtaining the benefit of the law of average, and also the practicability of driving those mills which are contributory to the washing process on the same mill line.

The first type of contributory mill to consider would be the *sheeting mill.* The purpose of this mill is explained in the early part of this paper. This mill, as a rule, is fitted with one fluted roll and one smooth roll. Disintegrated rubber is fed into the mill and the material worked to form the crepe-like sheets.

That high peak loads comparable to the disintegrating mill do not obtain, is readily appreciated. In fact the peak load requirements of the two classes of work, contrast strongly. The highest probable peak load on a sheeting mill is approximately one quarter of the probable peak load, on a washer mill used for disintegrating. The mean load on a sheeting mill approaches the probable peak requirement of this type of mill more closely than the mean load of a disintegrating mill approaches its probable peak requirement. On some installations the probable mean load of a sheeting mill may be as high as 60 per cent of the probable peak load requirement.

A combination then, of the washers used for disintegrating and the washers used for sheeting would promote efficient motor equipment, due to the fact, that the probable combined peak load would be proportionately lessened, and the probable mean load would be proportionately increased.

The next mill that could be considered as contributory to the washing process, is the breaking-down mill. The propriety of advocating the possibility of grouping this type of mill with the washer division may be questioned by many. It may be impracticable in some plants. This suggestion is made here in the hope that it may be helpful to some. Also in many plants the accounting schedule includes the breaking-down process as a function of the washing department.

The breaking-down mill is practically identical to a "warmer" mill, which will be described in a later section of this paper. The rolls on this mill are smooth, and heated. The crepe-like sheets are fed into this mill for the purpose of breaking down the granules, or the coagulated structure, and producing in its place a plastic, tenacious coalescent mass.

A study of the work to be done indicates that:

1. Peak loads are probable.

2. That the manner in which the operator feeds the material into the mill will have a direct bearing on the degree of peak load that will occur.

3. That the peak loads will be of appreciable time duration though gradually decreasing due to the fact, that as coalesence takes place, the mixture adheres to the rolls and some pressure is therefore always evident with this material between them; and also due to the frequent cutting off, and re-feeding by the operator.

4. Although peak loads will and do obtain on any rubber mill, the operator by using a small amount of judgment in feeding and in re-feeding, and by starting the charge at one side of the mill, and permitting it to feed across the face of the roll, can, without sacrificing efficiency in production, control the value of the peak loads within reasonable limits on breaking-down mills.

The probable maximum peak load of the breaking-down mill is approximately 60 per cent of the probable peak load of the initial process of the disintegrating mill, and the probable mean load on a breaking-down mill is approximately 44 per cent of the probable peak value. We now should be in position to condense our analysis as follows:

a. *Initial disintegrating.* Severe and sudden shocks. High peak loads of short duration. Intervals of friction load only, light load. Low, mean load factor. Short-time operation.

b. *Continued disintegrating.* Sudden shocks. Peak

loads of greatly reduced value. Fewer within a given time. Fewer intervals of friction load only. Higher mean load factor. Protracted time operation.

c. *Coagulating.* Peak loads of relatively low value. Fairly high mean load factor. Protracted time operation.

d. *Coalescing.* Sudden shocks. Peak loads of appreciably lower value than those obtaining during initial disintegrating and controllable by the operator. Few intervals of friction load only. Fairly high mean load factor.

(a) and (b) cannot as a rule be separated. (b) is usually a continuation of (a) on the same mill. But, with a number of mills performing disintegrating operations at one time on one mill line the maximum peak of the mill line will not be equal to the product of the peak load of one, times the number of mills in operation. Further, as it is not probable that all mills will be empty at the one time, the mean load will be higher.

If (a) and (b) operations can be combined with (c) all on one line the probable peak load will be appreciably less than the combined maximum peak loads of separate units. If to this can be added the (d) operation a further saving can be effected.

This committee believes that it is not advocating any departure that differs from practise followed by many, but that probably the subject has not been heretofore presented for discussion to a body of men outside of an industrial organization.

The committee submits for consideration the following basis of motor selection for washer mill application:

a. Group as many portions as production efficiency will permit, of any one general process into one mill drive. Preferably group, where practicable, portions whose load characteristics contrast.

b. Determine the probable reasonable peak load demand that will obtain in this group arrangement, with a defined understanding with the production department, what peak load will be considered as reasonable, based on a defined kind of stock, methods to be followed by operators to prevent abuse, the defined peak load value that will give a signal to the operators, and the peak load value which if exceeded will cause the protective device to stop the mill line.

c. Determine the probable mean load that will obtain in this group arrangement.

Then, select a suitable motor of:

1. Ample ability to carry through the peak load.
2. Sufficient thermal capacity to carry the mean load, with as high efficiency, and high power factor characteristics at this mean load as practicable.

A plan of this, or of comparable nature, should provide ample size of motor and eliminate any necessity for oversize of motor. It should also give to the rubber industry that honor of not only being the largest individual user of electric power, but also the most conserving user of electric power.

The grouping as suggested in paragraph (a) should provide a relatively high mean load factor per motor. This should result in a definite known efficiency for each drive. This feature is in contrast to data that show us the load factor of an entire plant, in per cent of nominal h. p. connected load. The power factor of an entire plant can be determined, but the electrical efficiency can not be determined from such data. The load factor of the entire plant in percentage of nominal h. p. connected is the combined mean load on all motors. Some motors may be underloaded and working at low efficiencies. Other motors may be overloaded and working at low efficiencies. Others may be operating under an average load condition that represents satisfactory efficiency.

The efficiency of the electrical equipment cannot be determined by the ratio of electrical input of an entire plant, and the nominal h. p. connected load, but if each application is analyzed in its entirety and motor selection is based on this analysis, each mill drive then will not only be supplied with ample motor equipment to carry on production, but it also will perform that work with high electrical efficiency, and will be a credit to the engineer of selection.

Mixers

Pure Rubber to Rubber Compound

The process up to this point has not changed the physical properties of the rubber. If these properties could not be changed, rubber would be of small value to humanity. Chemical changes can be made within the mass, with the result, that the otherwise useless mass becomes a product that is applicable to many uses. This process of chemical change is a function of mixing, compounding and vulcanizing.

Mixing sulphur with pure rubber, together with the application of heat and pressure, is an essential of vulcanizing. Mixing of other ingredients in addition to sulphur is essential to produce diversified product. The specific use to which the rubber will be put, determines the nature of the ingredient or ingredients used. Every ingredient added produces a chemical change in the rubber to enhance the value of the resultant compound, for that specific commodity of which it will be an important adjunct. In fact the importance of the rubber, and even the importance of rubber of that specific compound, may be such that without it, the article could not be produced.

Process. The cold plastic mass of pure rubber is thrown into the mixing rolls which are heated to a temperature consistent with the kind of rubber and its ultimate use. It is worked and warmed on the rolls of the mixers until the required plastic consistency essential for compounding is reached. The compounds are added a small amount at a time, the

working process being continued, until there is absolute uniformity of the mass.

The physical properties are now radically changed and the rubber is then sent to the store-room, as green-stock.

Motor Selection

In determining motor size, the operating *temperature* of the rolls should be taken into consideration, as the load on the motor is affected by the temperature of the rolls.

In determining motor size, the *kind* of rubber should be taken into consideration (kind of rubber, in this article refers to geographical source of supply). All other conditions being equal, one specific kind of rubber will produce peak loads 100 per cent greater than another specific kind.

In determining motor size, the fact that cold rubber is *thrown* into the mills, and that it is worked and warmed must all be considered. The cold rubber thrown into the mixing mill, produces high peak loads. This cannot be prevented; but if it is thrown into the mixing mill too rapidly, it produces excessive peak loads. This to a large degree can be corrected, by intelligent feeding, and a signal system.

In determining motor size, it should be noted that during the entire mixing operation the mass is worked. This working produces peak loads of prolonged time duration. The working is that operation where the rubber is cut diagonally from the roll, and re-fed into the rolls. The manner of this re-feeding has a direct bearing on the resultant peak load. This can be controlled by the operator to some extent, by starting the re-feeding at one end of the roll, and permitting the material to work across the face of the roll, and by a signal system which will warn the operator if he or others are feeding carelessly.

In determining motor size, the fact that after the initial feeding of cold rubber, subsequent feedings will be warmed, and in consequence the peak loads of re-feeding will be of lower value than the initial feedings of cold rubber, should be taken into consideration.

In addition to the variables involved in the process, the characteristics of each mill must be considered. Large diameter rolls result in a smaller angle of approaching stock, hence a larger wedging force in proportion. This results in higher peak loads, large bearing pressures, increased friction losses. The ratio of friction between the rolls has a direct bearing on the load demand, and must be included in any analysis of conditions, determining suitable motor size.

The number of mills to the mill line should be considered, taking advantage of the law of average. Where a number of mills are involved on one line, the peak load will not equal the peak load of any one, times the number of mills. The fact that a number of mills may be on one line, some working on one kind of rubber and other mills on another kind of rubber should be considered, as the resultant load will not be the product of the heaviest kind of load, times the number of mills, but will be the resultant or mean peaks of the combined heavy kind of load, and the lighter kind of load.

This committee has reports which indicate maximum peak loads on mixing mills as high as 3.5 h. p. per linear inch of roll face. It has been reported that the following rule has been applied; whether it is in actual use, the committee cannot determine.

Take maximum h. p. per inch of roll face 3.5.

Divide this by the value of the ratio between the normal full load torque rating of the motor, and its pull-out torque value.

Multiply by number of inches of linear roll face.

Answer equals nominal h. p. rating of motor to select.

Assume, pull-out torque of motor $2\frac{1}{2}$ times full load rated torque.

Assume, 360 linear inches of roll face.

Then $\dfrac{3.5 \times 360}{2.5} = 504$ h. p., nominal rating, would be the answer, or a nominal rating of 1.4 h. p. per linear inch of roll face.

But, will this apply to every mixing mill line, irrespective of kind of rubber, all diameters of rolls, all ratios of friction between rolls, all temperatures and all pressures that may be involved?

If this is the absolute maximum under the most severe conditions, then the problem becomes one simply of selecting a motor that will surely be large enough and in many installations will be oversize. This committee believes that the problem of the engineer is to equip each mill line with a suitable size of motor as determined from an analysis of the load conditions that obtain on that line.

Another report of record, which this committee received, is as follows:

Mixing Mill Line Loads

Highest 30-minute average peak load	100 per cent
Highest 5-minute average peak load	120 per cent
Highest 1-minute average peak load	155 per cent
Highest instantaneous peak load	215 per cent

This condition could readily obtain on a specific drive on a specific stock under specific working conditions; but, can it be applied as a general rule for the equipping of all mixing lines with motors?

The following list of installations is submitted, not as a basis of selection nor as a basis of approved practise, in that this committee does not have the detail of each installation, but it does indicate that the formula quoted is not followed generally, and it also appears to indicate in some instances at least, that the work to be done by a specific mill line had been taken into consideration.

We are not including the addresses of these installations in that this has no bearing on the situation from

the engineering standpoint. They however include installations in the U. S. from coast to coast, and also Canada, France and Japan.

MIXER LINE INSTALLATIONS

Number and Size of mills	Nominal H. P. Rating of Motor	Nominal H. P. Per Linear Inch of Roll Face
3—40 in., 3—36 in.	150	0.66
3—60 in.	375	1.04
3—60 in., 1—36 in.	250	1.16
3—20 x 60 in.	200	1.11
9—40 in.	375	1.04
5—42 in., 5—60 in.	500	0.98
8—48 in.	200	0.595
6—36 in.	150	0.696
8—60 in.	700	1.46
7—60 in.	450	1.07
6—84 in.	500	0.9925
9—84 in.	800	1.055
4—38 in., 1—44 in., 1—46 in., 1—54 in.,	200	0.675
3—18 x 60 in.	200	1.11
6—60 in., 1—38 in., 1—40 in.	250	0.57
3—32 in., 1—40 in.	150	0.84
2—18 x 48 in.	100	1.04
4—60 in.	300	1.25
4—20 x 54 in.	250	1.155
1—60 in.	100	1.67
2—60 in.	250	2.08
3—60 in.	250	1.39
3—16 x 45 in.	150	1.11
6—84 in.	600	1.19
2—18 x 46 in., 1—18 x 20 in.	150	1.29
2—16 x 48 in., 1—18 x 30	150	1.19
5—14 x 36 in.	100 (reclaiming)	0.555

This list could be continued into hundreds of installations without affecting the conclusion as a whole.

The committee concludes that satisfactory motor size selection cannot be made for each specific mill line by generalizing on limited data. Each mill line should be equipped with motors on an engineering basis; the engineer to have complete data of requirements and to select the size and type of motor which analysis of the conditions that will obtain on that specific drive calls for. No general rule based on nominal h. p. per lineal inch of roll face is applicable. Motors cannot be satisfactorily selected on an arbitrary nominal h. p. rating, which rating means nothing more nor less than that a given motor will carry a certain load continuously with a temperature rise of a certain value.

In general milling operations a uniform even load does not exist on any one mill line. It is not only a varying load, but it is a widely fluctuating load. (This is not intended to apply to the total load of the plant, or to the plant load factor. The plant load factor is the mean load of the entire plant. It is the result of the law of average of the entire plant. We are interested in the equipment of one mill line in that plant and the one mill line is therefore the point of discussion. There is a wide difference). This widely fluctuating load is the problem; how to equip it with motors effectively to maintain production, and also economically.

In a paper presented by Mr. H. C. Stevens of Akron, Ohio, before the Ohio Section of the The National Electric Light Association, meeting of January 21, 1920, is shown an estimated average power factor for four rubber manufacturing plants of 67 per cent. This may include lighting and other unity power factor loads. In any event, can it be improved? A 67 per cent power factor simply means, that all equipment used in producing, transforming and transmitting the power must be of 50 per cent greater capacity than the actual power supplied.

In another table submitted by Mr. Stevens, covering seven rubber manufacturing plants, the maximum demand in percentage of connected load, varies from 39.5 per cent on the lowest, up to 78 per cent on the highest, and on the largest installation shown by the table, the maximum demand is only 89 per cent of the total connected load. This was in August of 1919 at which time the production of rubber was large.

In the same table by Mr. Stevens, we find in six rubber manufacturing plants, an annual load factor based on 8760 hours, for the year 1918, of 30.9 per cent and for the year 1919 on seven plants of 32.7 per cent. Based on a working day of eight hours and a working year of 300 days, this factor would be high, but when compared with other data in the same table it would appear that the working time was in excess of eight hours per day. It would be interesting to know the load factors of the same plants for the year 1920.

A partial analysis or generalizing would indicate the possibility of more efficient motor equipment. Every dollar tied up in oversize or unsuitable motors, and in contributory equipment represents just that much waste. Every unnecessary loss in operation of oversize or unsuitable motors, and in contributory equipment represents just that much waste.

If such waste does obtain we believe that the remedy lies in engineering. Let the electrical engineer look upon each size and type selection as a specific problem. If he has done so in the past, may he continue and with determination analyse even more carefully in the future.

To select a motor large enough, from a given maximum rule, with a constant that is conservative even for the most severe condition, can be the function of anyone, but the selection of a suitable motor for a specific drive, can only result from the careful analysis of complete facts by the engineer. In his analysis, he has, and will continue to consider the following:

a. The mechanical characteristics of each mixing mill. Length of roll face. Diameter of rolls. Ratio of friction between rolls. Width of opening between rolls.

b. *Kind* or preferably *kinds* of rubber on one mill line. Pressures on rolls. Temperatures.

c. That operators can be taught efficient feeding. That this be an understanding with the production department. That a signal system can be used to warn the operator against injudicious feeding. That if the operator ignores the warning and attempts to force, and abuse the mill, a protective device can be used to shut down the mill line. The load on which the signal is to give warning, and the load at which the protective device is to operate would be determined in cooperation with the production department.

d. Grouping of mixer mills to the greatest number permissible on one line, without sacrificing production, and grouping, as far as is consistent, mills on various *kinds* of stock, and obtain that benefit which will result from the law of average, using a constant that the engineer will develop from his own plant operation similar to the typical table of constants given in this paper under the subject of washers.

e. After determining all of the foregoing factors, the engineer will be in position to determine the peak load requirement, and also the mean load for a given period of time. From characteristic performance curves he will select that motor which has sufficient maximum torque capacity to handle the maximum torque requirement of that specific mixer mill line, and will select that type of motor which will not only do this, but which also will have sufficient thermal capacity to carry the mean load, and will do this efficiently and with a minimum of reactive current.

Atmospheric Conditions of Mixing Rooms. Mixing is usually attended by dust of the compounding ingredients. Some is highly abrasive, some is only slightly so, in any event it is preferable to so plan the installation that this dust cannot prove detrimental to the motor bearings.

The situation has been somewhat accentuated since the advent of organic accelerators, ingredients that are added to hasten vulcanization, as this dust is frequently injurious to health. Probably the best solution is an installation of a dust collecting, and ventilating system with a motor-operated blower to remove fumes and dust, thereby protecting the operators and machinery alike.

In the foregoing the subject has been one of mixing rolls and does not refer to batch mixers or mixing machines.

This committee has no test data applying to the mixing machine and can make no comments with reference to peak load demands.

The manufacturer lists two sizes in their literature as follows:

Size	Batch Capacity Crude Rubber	H. P. of Motor Individual Drive	Average H. P.
3	70 lb.	75	50
9	210 lb.	200	125

This committee would be glad to receive from any engineer any data he can give us with reference to the power requirements of the mixing machine.

Warmers

The green-stock is accounted back to the storeroom from the mixer room and after a "seasoning" is accounted out to other departments, such as calender room, tube room, etc. Warming is the initial program in the various departments where it is used. The warmer mill discussion is closely allied in this paper to that of the mixing mill, in that the machine itself is practically identical to a mixing mill and the motor problem is similar.

Process

The cold green-stock is thrown into the warmer to warm the stock to render it soft and pliable so that it can be calendered readily.

In the mixing operation the stock was changed from a plastic condition to a tough, resilient product.

In addition to warming, the stock is worked on the warmer rolls to affect its consistency throughout uniformly.

Motor Selection

The fact that warmer mill is practically identical to the mixer mill makes all suggestions that apply to one, apply to the other, with two possible exceptions.

1. The cold green-stock thrown into the warmer does, as a rule, owing to its less plastic nature, cause higher peak loads than the cold pure rubber thrown into the mixer.

2. There is less probability of its being practicable to combine on one mill line a number of warmers, or of having warmers on one mill line handling various kinds of stock at the one time. It can be done in many instances, and it is advisable to take advantage of the opportunity wherever practicable.

In evidence that in some plants at least, a general rule is not applied in motor size selection, we add the following table:

Size of Warmer	Nominal H. P. Motor Rating	Nominal H. P. Per Linear Inch of Roll Face
1—18 x 36 in.	40 h. p.	1.11
1—16 x 36 in.	25 h. p.	0.695
1—18 x 36 in.	50 h. p.	1.39

Conclusions

The basic idea of this committee is to equip rubber mill machinery with motors on an engineering basis. The committee believes that with the large amount of power involved more efficient motor equipment can obtain in many plants if we have a plan to provide the proper cooperation.

The committee concludes that many engineers have their own plans that they execute faithfully and with success.

The committee does not advocate a plan, simply

on account of the plan, but if one can be developed that will be helpful to the engineers in the rubbe industry as a whole, the committee then would favor it and gladly cooperate, not for the success of the plan as a plan, but for the benefit that would result to the engineers of the rubber industry.

Safety Stop

Hazard

The *danger* which is prevalent in the various operations of *general milling* or *basic operations* is due to the tenacious character of rubber in its plastic state.

The operator is very likely at any time to become caught in the folds of the rubber and drawn into the rolls. He may be caught on either hand, or both hands may become entangled. The safety mechanism should be, therefore, of such a nature that if both hands are entangled he can trip the mechanism with his head. The safety mechanism of all machines on any one mill line should be so interconnected that any operator on that mill line may stop the entire mill lines from his own mill should another operator become caught.

Although this is a dangerous condition under which these men must work it has one redeeming feature. The operator does not become caught directly in the rolls. If so then he would be damaged to some extent no matter what device were used for the stopping of the mills. He is caught in the folds of the rubber some several inches from the point of contact of the two rolls.

If a suitable type of safety stop is used and if prompt action is taken either by the operator who is caught, or by one of his companions at an adjacent or nearby mill, or in fact at any mill along that line, it is entirely within reason to obtain a stop sufficiently quick to prevent damage to the individual.

Safe Stopping Distance

The diameter of the average roll is 22 in. A diagram would indicate clearly why the maximum stopping time of the roll must not exceed approximately 40 angular degrees of periphery travel between the time that the man is actually caught and the time in which the mill is brought to rest.

This brings the actual stopping time available from the moment that the safety mechanism is tripped until the mill is actually at rest to about 20 angular degrees of periphery travel. Put this in terms of inches of periphery travel and it gets to that short distance of 4 in. This should be measured by a chronograph in that the eye cannot detect this with a sufficient degree of accuracy.

If a device will stop the mills within 4 in. of travel of the roll periphery it can be depended upon as a rule to prevent damage to the operator.

Suitable Stopping Device

This committee has knowledge of only one basic way in which this stopping can be obtained.

The means for this service consists of a device which will disconnect the prime mover, which is a high inertia load, from the driven mill line, which is a low inertia load, and which device will simultaneously apply a brake to the driven load.

With devices of this nature sufficiently quick stops can be obtained without any probability of damage to the equipment through the shock of this quick stopping. Second and most important the stopping can be done quickly and with sufficient speed to consider such a device as a safety stop—not simply a stop.

Clutch brakes are made in both the magnetic, and the air type. The magnetic clutch brake has been most generally used. It is an easy matter to "tie in" the magnetic clutch brake type with the electrical system. It also undoubtedly has that advantage of being most simple in structure.

Many schemes have been tried which do not contemplate disconnecting the motor mechanically from the mill line.

Plugging the motor to reverse it to bring it to a stop has been tried, but this has never met with any degree of success. Even were it successful in stopping quickly it would still have the disadvantage that it depends on an outside source of supply for its ability to stop the mills at a critical moment. This alone would militate against it.

The one other method that has been tried to some extent and which is the only one so far that we can find that begins to approach a safety stop, is that one which contemplates the opening of the motor circuit and the applying of a magnet-operated mechanical brake.

However, when it is considered that at least 85 to 90 per cent of the stored energy of angular rotation of the combined motor and mills is in the motor, it can readily be appreciated what a large size this brake must be in order to absorb the large amount of stored energy that is in the motor, in order to bring the motor and the mills to a stop, that begins to approach that stop which would be considered a safety stop in every sense of the word.

We have found for example, on a 50-h. p. motor where the normal motor torque is 510 lb-ft., that the torque required to bring mills to a stop within a travel of 6 in. of the periphery of the rolls means an energy absorption equal to 2380 lb-ft. This means a ratio of required torque on stopping to normal torque of 4.65.

On a 200-h. p. motor where the normal motor torque is 2050 lb-ft. the torque required for 6-in. stop is 10,700 lb-ft. or a ratio of 5.2 to 1.

On a 500-h. p. motor, the normal motor torque lb-ft. is rated at 5,100, whereas the torque required for a 6-in. stop of roll periphery travel is 15,500 lb-ft. A ratio of 3 to 1.

The above refers to motors operating at a speed of 514 rev. per min.

With a roll diameter of 22 in. and a roll speed of 18 rev. per min. a 6-in. stop on that roll would require that the motor be stopped in 2½ revolutions, or in about 0.58 second.

Complete consideration of these figures will indicate to the engineer the size of brake that would be required to bring the motor and the mills to rest within a time lapse that would be safe. It will also show the heavy strain that must be imposed on the rotor structure, in that the mechanical brake must be attached to the rotor shaft, whereas practically all of the energy of rotation is in the rotor proper.

Stopping Test Results

The following tests were made on a mill drive including two Farrel 22 x 60, back roll 23.07 rev. per min. Front roll 18.03 rev. per min. Friction ratio 1.27.

The motor was a Westinghouse type C. W. 1002, 250-h. p. 580 rev. per min.

Tests were made both with a device which was arranged for disconnecting the motor mechanically from the mill line and applying a brake, and with the other device arranged for opening of the motor circuit and applying a brake to stop both motor and the mills.

Stopping with no safety device the roll travel was 240 in.

Stopping by disconnecting the motor mechanically from the mill line and permitting the mill line to come to rest against its own friction the travel of the front roll was 103 in.

Disconnecting the motor from the source of supply electrically and applying the brake to stop the motor and the mills the travel of the front roll was 40 in.

By using the combination which disconnected the motor mechanically from the mill line and applying the brake to the mill line only, the travel of the front roll was 8 5/8 in.

The above test was conducted with all of the mills empty. This would be the worst condition that could obtain for the reason that the friction on the mill line would be low. This condition could not obtain at a time when safety stop would be required for the reason that no one is likely to be caught under this condition.

The worst condition under which an operator can be caught is that one which obtains with only one mill operating and all of the other mills idle. This presents an opportunity for an operator to be caught and at the same time with a minimum of load on the mill that could be depended upon to assist in quick stopping.

The following test data were obtained with one mill loaded, the load on the motor being 130 h. p.

Stopping naturally by simply disconnecting the motor from the line electrically and applying no outside force the front roll travel was 75 in.

By disconnecting the motor from the mill line mechanically and applying no brake to the mill line, the mill lines come to rest with a travel of the front roll of 16 in.

By disconnecting the motor from the source of supply electrically and applying the brake to stop the motor and the mill line simultaneously the front roll travel was 16⅜ in.

By stopping with the device which disconnected the motor from the mill line mechanically and applied a brake to the mill line only, the front roll travel was 4⅛ in.

Compensation

This is a very important question. It is one where even human life is involved. Some years ago before safety stops were used as generally as today every mill had its quota of cripples, and even today you will find an unusual number who were injured through being caught in this plastic material and drawn into rolls.

The Industrial Commission as a rule favors the worker, and the employer must pay heavy indemnities varying in many States from approximately $120.00 minimum for loss of the ring finger at the second joint up to a maximum of approximately $5,000.00 for the loss of an arm at or near the shoulder. In addition to this the employer must pay all doctor and hospital bills.

Further, there is a loss to the community of the man's idle time.

On the other hand,there is no question but that it would be much more fitting had the accident never occurred. We question if there is any other one feature on which the engineer can be more careful than in the selection of suitable accident preventive devices in connection with this class of work.

Recommendations

It is the recommendation of this committee that the most suitable manner in which safety stops can be electrically connected is in such manner that when the safety mechanism is operated the entire mill line drive including the motor will come to rest; whether or not the motor comes to rest as quickly as the mill line is not important, but that it also be so interlocked with the motor control system that even the motor cannot again be restarted until all safety devices have been placed in the "run" position, so as to have assurance that all workmen are clear of the mills, is important.

We favor also an arrangement, or combination of arrangements, of such nature that the operator who has charge of restarting of the mills cannot restart the mills at least, even though he may be able to start the motor, excepting from such location that the entire front of the mill line is visible to him, so that he can be assured that all is "clear" before he actually puts the mills in operation. We believe this to be important as it would eliminate entirely possible accidental restarting of mills.

Phase Compensation*

With Special Reference to Polyphase Motors

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In a series of articles which appeared in the *Electrical World* in 1913, the author dealt, at some length, with phase control in general, with phase compensation in synchronous motors, and with the only method of controlling the power factor in single-phase motors with shunt characteristic which has, to date, become of practical value; but other means of controlling the phase difference in nonsynchronous single-phase motors are known and these will now be considered before dealing with phase control as applied to non-synchronous polyphase motors.

All the figures show two-pole machines.

7. Controlling the Phase Difference in a Single-phase Motor with Shunt Characteristic by Changing the Phase of the Exciting e. m. f.

The method of controlling the power factor of a single-phase motor which has been applied in practise

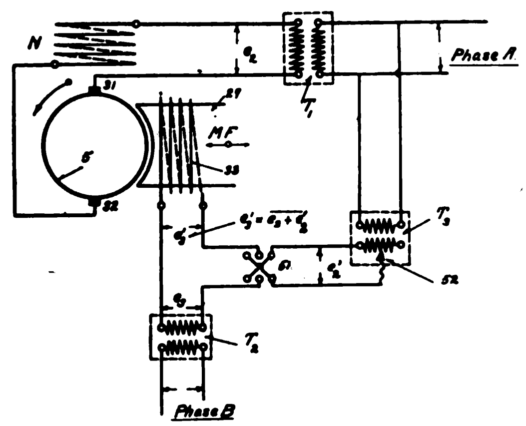

Fig. 33—Neutralized and Compensated Shunt Conduction Single-Phase Motor Operated From a Two-Phase Supply

with the greatest success consists in changing the phase of the exciting e. m. f. relatively to the phase of the working e. m. f. This method is illustrated in Fig. 33 as applied to a neutralized, single-phase, shunt, conduction motor. The armature circuit 31, 32 of this machine is connected to one phase of a two-phase supply, while its exciting winding 33 is connected to the other phase. Normally, there would, therefore, be a quadrature relation between the working and the exciting e. m. fs. and all but phase coincidence between the former and the motor or exciting flux. This condition would make the back e. m. f. in the armature circuit practically cophasal with the working e. m. f. and would result in a poor power factor because of the impedance of the armature circuit. To correct this condition, it is now usual to change the phase of the e. m. f. applied to the terminals of the motor field exciting winding 33. In Fig. 33, this is done by impressing on the field winding 33 an e. m. f., one component of which is derived from phase *B*, while the other is taken from phase *A*. Almost any degree of phase control can be obtained in this way, simply by changing the magnitude of the component derived from phase *A*.

Now, the real object of changing the phase of the exciting e. m. f., and thereby changing that of the exciting flux, is to change the phase of the back e. m. f. in the armature circuit. The magnitude and phase of the armature working current are determined by the magnitude and phase of the vectorial difference

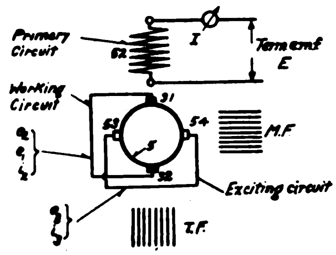

Fig. 37—Self-Excited Single-Phase Shunt Induction Motor

between the working and back e. m. fs. and by the time constant of the armature circuit. In applying the phase-controlling method under reference, one aims to so place the phase of the vectorial difference between working and back e. m. fs. that, notwithstanding the time constant of the armature circuit, the phase of the armature current will, nevertheless, closely approach that of the terminal e. m. f. and will not depart too far from that of the motor or exciting flux.

A close coincidence between current and terminal e. m. f. of course spells high power factor, but it is inadvisable to push phase compensation so far as to produce a material phase difference between armature current and motor flux, for the reason that the greater this difference, the smaller will be the torque per ampere.

The application of this same principle to the self-excited, single-phase, shunt, induction, commutator

*Presented before the St. Louis Section A. I. E. E., October 27, 1920.

This paper supplements a series of articles by Mr. Fynn, published in the *Electrical World*, July 5, 12 and 19, 1913, which had special reference to single-phase motors.

motor shown in Fig. 37, is of more practical interest because not requiring a polyphase supply, and is illustrated in Fig. 38. It is known that such a machine produces its own exciting e. m. f. e_3 and that the phase of the latter is displaced by about 90 degrees with respect to the terminal, or working e. m. f., as shown in Fig. 54. This being so, the phase of the effective

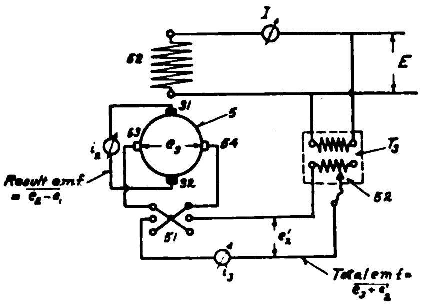

FIG. 38—SELF-EXCITED SINGLE-PHASE INDUCTION COMMUTATOR MOTOR WITH SHUNT CHARACTERISTIC AND ARTIFICIAL PHASE COMPENSATION

exciting e. m. f. along the axis 53, 54 can, in this case, be changed by injecting into the circuit along said axis an e. m. f. of same phase as that of the supply.

The complete phase diagram of the motor shown in Fig. 37 is seen in Fig. 55, and it is thought that a short discussion of this diagram will be of use in elucidating some phase-controlling methods not heretofore discussed. In order to avoid undue complication of Fig. 55, some of the vectors have been omitted.

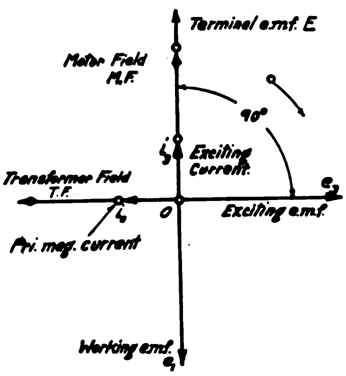

FIG. 54—APPROXIMATE PHASE DIAGRAM OF A SINGLE-PHASE SHUNT INDUCTION MOTOR, WITH SELF EXCITATION

One point to which it is desired to draw particular attention is the presence in the exciting circuit 53, 54 of the small e. m. f. $G J$, the effect of which is to shift the phase of the effective e. m. f. $O J$ in the exciting circuit, and therefore the phase of the exciting flux $O L$ and of the back e. m. f. $O M$, in a direction to *improve* the power factor of the machine. The e. m. f. $G J$ which provides this compensating feature in the motor shown in Fig. 37 is generated in the rotor conductors along the axis 53, 54 by rotation of said conductors in the leakage field produced by the armature ampere turns along the rotor axis 31, 32. Without this e. m. f., this type of motor would be of no practical utility. It is interesting to observe that, independently of the magnitude of the rotor leakage flux, and therefore of the rotor impedance, this self-compensating e. m. f. is of such magnitude, *at synchronism*, as to eliminate entirely the effect of the rotor impedance. Because this e. m. f. is dependent on the speed of the rotor, it diminishes as the slip of the motor increases and at sub-synchronous speeds, the rotor impedance along the armature axis 31, 32 is not entirely compensated for by the effect of the e. m. f. in question. The power factor of the motor shown in Fig. 37 is, nevertheless, smaller than unity, even at synchronism, for the reason that the self-compensating e. m. f. $G J$ does not, at that speed, produce a leading current in the rotor along the axis 31, 32 and does not, therefore, compensate for the lag in the primary 52, which lag is due to the magnetizing cur-

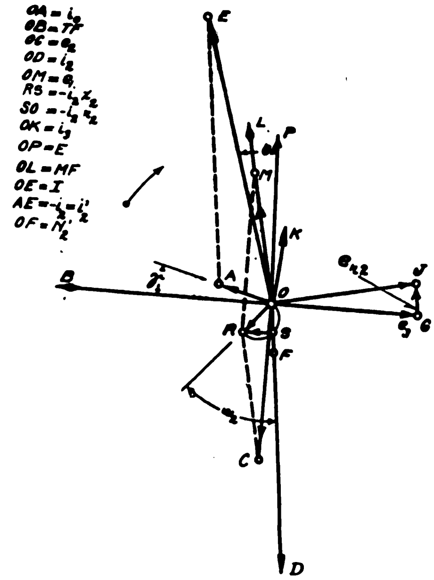

FIG. 55—EXACT PHASE DIAGRAM OF A SELF-EXCITED SINGLE-PHASE SHUNT INDUCTION MOTOR

rent circulating in the stator inducing winding. At super-synchronous speeds, the self-compensating e. m. f. does cause the secondary current to lead the working e. m. f. in the rotor axis 31, 32 and thus does, at least partly, compensate for the magnetizing component of the stator.

Referring back to Fig. 33, it will now be apparent that no such self-compensating feature exists in that machine, with the result that such a motor would be quite useless without the application of external phase-controlling means and that the whole phase displacement of the back e. m. f. must be brought about by external means.

The other point in connection with Fig. 55 to which particular attention should be drawn, is the fact that within the working range of the machine, the phase of the working current $O D$ does not materially depart from the phase of the working e. m. f. $O C$, and the reactance drop $R S$ is substantially in quadrature with the self-compensating e. m. f. $G J$.

8. Connecting a Condenser in Parallel with the Terminals of a Motor

It is a question whether this method should be included in a discussion of means for controlling the phase difference in single or polyphase motors, for the reason that it changes nothing within the motor it-

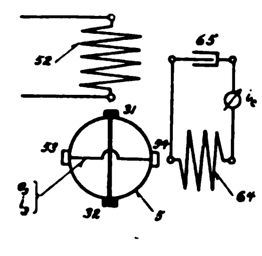

Fig. 56—Self-Excited Single-Phase Shunt Induction Motor with a Condenser in Inductive Relation to the Field Circuit

self, but merely compensates for the effect of the motor as a whole on the circuit to which it is connected. This arrangement calls, at equal voltages, for condensers capable of handling a current of a magnitude equal to that of the reactive component of the total current absorbed by the motor. Such condensers can be connected to the terminals of the machine either directly or with the interposition of step-up transformers, and they must be built for the same frequency as the motor. This method is not looked upon as a practical one, for the reason that such condensers as are available for this

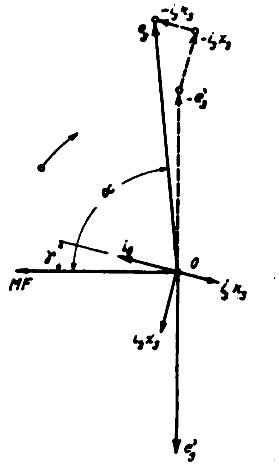

Fig. 57—Phase Diagram of Field Circuit of Motor of Fig. 56 with Condenser Disconnected

purpose are still prohibitive as to price. Dynamic condensers may be, and sometimes are, used in the same way, but here again the question of price interferes in most cases.

9. Controlling the Phase Difference in a Single-Phase Motor by Connecting a Condenser in Inductive Relation to the Field Circuit

One such arrangement, which is diagrammatically shown in Fig. 56, falls strictly within this investigation and is quite interesting. If it has not come within the range of practical politics, it is for the reason that it relies on condensers.

Figs. 57 and 58 show how the phase-controlling device of Fig. 56 operates. The phase diagram of Fig. 57 refers to any kind of a transformer, the secondary of which is on open circuit. The e. m. f. applied to the primary of this transformer is e_3, the magnetizing current is i_3, the transformer flux is $M F$ and e_3' is the secondary e. m. f. The terminal e. m. f. e_3 must equal and oppose the vectorial sum of an e. m. f. of same magnitude as e_3' induced by $M F$ in the primary winding, of an e. m. f. $i_3 x_3$ induced in the primary by the leakage flux due to i_3 and of an e. m. f. equal and opposed to the ohmic drop $i_3 r_3$. The result is that while the phase difference between $M F$ and e_3' is 90 degrees, that between the flux $M F$ and the terminal e. m. f. e_3 is less than 90. Now, in the ordinary self-excited, single-phase, in-

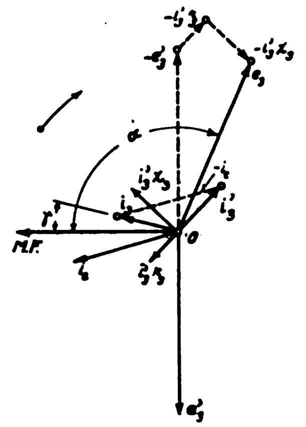

Fig. 58—Phase Diagram of Field Circuit of Motor of Fig. 56 with Condenser in Circuit

duction motor, with shunt characteristic, such as shown in Fig. 37, the open circuit transformer conditions illustrated in Fig. 57 obtain along the motor field axis 53, 54 with this peculiarity that the e. m. f. impressed on the primary of this transformer is generated in the machine itself by rotation of the rotor conductors in the transformer field appearing along the axis of 52. In the ordinary machine, there is no secondary winding in the axis 53, 54, but as long as the conditions are considered in which this winding is on open circuit, it is, of course, immaterial whether said secondary exists or not. Suppose now, that a secondary winding such as 64 of Fig. 56 is placed in inductive relation to the primary, which is the rotor winding 5 along the axis 53, 54, and that this secondary is closed on a condenser 65. The changes brought about by this addition are shown in Fig. 58 where it has been assumed that the condenser 65 will take the leading current i_c when e_3' is impressed on its terminals. Since the flux $M F$ must be preserved in order to counterbalance the e. m. f. impressed on the terminals of the primary 5, the latter will take a current i_3', equal

to the vectorial sum of the magnetizing current i_3 and of another current equal and opposed to i_c. This brings about a very material change in the phase of the current in the primary 5 along the axis 53, 54, with the result that the ohmic drop and the reactance voltage in this winding also change their phases. The e. m. f. impressed on said winding, which in Fig. 56 is the exciting winding of the motor, must, as before, equal the vectorial sum of e. m. fs. equal and opposed to e_3', $i_3' r_3$ and $i_3' x_3$.

Because of the changed phase relations just referred to and brought about by condenser 65, the phase difference between the voltage e_3 at the terminals of the primary 5 and the flux $M F$ will be greater than 90 degrees, instead of less than 90, as in Fig. 57.

Referring now to Fig. 55, it is seen that the effect of the self-compensating e. m. f. $G J$ is to increase the phase difference between the exciting e. m. f. proper which is e_3 and the motor flux $O L$. From this, it appears that the condenser 65 of Fig. 56 produces the same result, although it does so in a totally different manner.

In the motor of Fig. 37, ohmic resistance in the rotor along the axis 53, 54 is detrimental to the power factor in that it decreases the phase difference between the exciting e. m. f. e_3 and the motor flux $M F$, as may be seen from Fig, 57. By adding the winding 64 to this machine and connecting it to a condenser 65, the effect of ohmic resistance in the rotor axis 53, 54 is reversed, as is shown by Fig. 58.

The addition of the winding 64 and the condenser 65 of Fig. 56 may also result in a change in the speed of the motor. Because of the altered phase relations within the rotor exciting circuit, brought about by the use of the condenser, the same flux $M F$ can be produced with a smaller exciting e. m. f. e_3 as appears from a comparison of Figs. 57 and 58. Conversely, if the exciting e. m. f. remains unaltered, it will produce a larger $M F$ and thus bring about a material reduction in the speed of the motor. The conditions indicated in Fig. 58 will actually be met by such a reduction in the motor speed as will reduce the exciting e. m. f. to a value which will generate a motor field of a magnitude sufficient to produce, at said lower speed, a back e. m. f. of the required value.

The condenser 65 must be built for the same frequency for which the motor is made and may, of course, be connected to the winding 64 with, or without, the interposition of a step-up transformer. If the winding 64 is located on the stator in an axis other than that of the motor field, then the effect of the condenser 65 will be twofold. A winding so located can always be replaced by one in line with the motor field and another in line with the armature axis, each being connected to a separate condenser. The effect of the winding in line with the motor field axis will be as just described, while the other winding will simply compensate for the magnetizing component in the stator winding 52.

The fact that the phase angles and the magnitude of some of the e. m. fs. have been exaggerated in Figs. 57 and 58, in order to produce clear diagrams, does not vitiate the conclusions except as to degree. It should further be noted that the value of the current in the primary 5 along the axis 53, 54 has been kept the same in the two diagrams. It is clear that this current may, in practise, be given any permissible value. If the phase of the primary current is made to lead that of the motor flux by 90 degrees, then the magnitude of the reactance voltage exerts a maximum, and that of the ohmic drop a minimum, influence on the phase difference between $M F$ and e_3. In case the primary current is made of opposite phase to the motor flux, the influence of the ohmic drop becomes a maximum and that of the reactance voltage a minimum.

While the action of the condenser 65 has been explained with particular reference to the self-excited, induction, commutator motor with shunt characteristic, this method of phase control is applicable to other types of motors, for instance, to the corresponding squirrel-cage or slip-ring machine, where it operates in exactly the same way.

10. Controlling the Phase Difference in a Single-Phase Motor with Shunt Characteristic by Introducting into the Armature Circuit an E. M. F. of a Phase Opposed to That of the Reactance E. M. F.

The injection of a compensating e. m. f. into the exciting circuit as shown in Fig. 38 and the use of a condenser in inductive relation to the exciting circuit as shown in Fig. 56 both aim to control the phase difference in the machine in what appears at first sight to be a somewhat roundabout way. A more direct method is that which consists in injecting into the armature circuit an e. m. f. which will oppose the reactance e. m. f. in that axis. This proposition can also be looked upon as a direct means for changing the phase of the resultant back e. m. f., in which case, the injected e. m. f. is dealt with as a component of the back e. m. f. While theoretically simpler than the methods shown in Figs. 38 and 56, yet this scheme has little practical value in connection with single-phase motors. In the case of a machine such as that of Fig. 33, it is as easily applied as the one which achieves the result by altering the phase of the motor field. The reason for this is, however, the availability of a polyphase system of distribution. On single-phase circuits, the application of this scheme would require the addition of a phase converter or similar device. There are, however, other serious drawbacks to this arrangement; it adds to the resistance of the armature circuit and thereby lowers

the efficiency of the machine and it also adds to the reactance of that circuit, thus making it necessary to inject a compensating e. m. f. which will not only take care of the reactance of the rotor circuit along the armature axis, but also of the reactance of the source from which the compensating e. m. f. is derived. The addition of this external reactance is also unfortunate in that it makes it necessary to change the external compensating e. m. f. with changing load if the power factor is to be kept constant.

11. Controlling the Phase Difference in Single-Phase Induction Motors with Shunt Characteristic by Injecting a Unidirectional e. m. f. into the Induced Member

When a single-phase induction motor of the type shown in Fig. 37, or of the squirrel-cage type which is its equivalent, is in operation the resultant flux in the machine is nearly constant in magnitude and revolves in synchronism with the line frequency; this flux is produced in part by the inducing, and in part

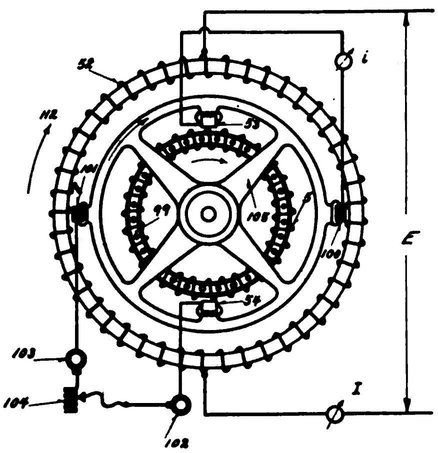

Fig. 59—Single-Phase Shunt Induction Squirrel-Cage Motor With Unidirectional Excitation (Stationary Inducing Member)

by the induced member. To fix ideas, consider a squirrel-cage, single-phase motor with stationary inducing member, as shown in Fig. 59. The inducing winding 52 is connected to the supply, and the rotor, provided with the squirrel-cage winding 99, revolves in a clockwise direction at a speed slightly below the synchronous. At no load, the rotor has only to overcome windage and friction losses and the slip is consequently very small. The total magnetization of the machine is produced partly by stator, and partly by rotor currents. The former are of line frequency, while the latter are of line plus rotor speed, and of slip frequency. When the magnetization produced by the stator is at its maximum, then the magnetization produced by the rotor is coaxial with, but opposed to, the former and the axis of the resultant revolving field $R F$ in the motor coincides, at that instant, with the axis of the inducing winding on the stator. One-fourth of a period later, all of the motor magnetization is produced by the rotor and the axis of the revolving field in the motor has traveled through 90 electrical degrees.

This is true whether the motor revolves at a synchronous, or a nearly synchronous, speed. As the rotor speed diminishes, the frequencies of the rotor currents change and thus keep the speed of the revolving flux constant. That component of said flux which is produced by the rotor, and often referred to as the speed component, however, diminishes with decreasing speed which causes the end of the revolving flux vector to follow a more and more elliptical, instead of a circular, path.

Now, if it were possible to produce the revolving flux required by this motor by suitable external means, all magnetizing currents could be eliminated from its stator as well as from its rotor, while the character of the machine could conceivably be left unchanged. The method under reference accomplishes this by means of a commuted winding 5 located on the rotor and brushes 53, 54 cooperating with same.

A direct current introduced into the winding 5 by means of the brushes 53, 54 will produce a unidirectional magnetization, the axis of which, will always coincide with the axis of said brushes, or bear a fixed relation thereto, independently of any movement of the rotor conductors. The method consists in supplying a unidirectional e. m. f. to the brushes 53, 54 and revolving these in the same direction as, and in synchronism with, the revolving flux of the motor, that is, in synchronism with the line frequency. An additional condition for best results is that the axis of said brushes shall, at every instant, coincide with the axis of said revolving field.

In the motor shown in Fig. 59, the revolving flux rotates in a clockwise direction, as indicated by the arrow 112, the rotor necessarily revolves in the same direction and the brushes are, therefore, also rotated in a clockwise direction. The space position of the brushes at any instant is determined by the consideration that when the magnetization produced by the stator is at its maximum, the axis of the revolving flux coincides with the axis of the stator inducing winding 52. At that time, the stator magnetizing current is practically at its maximum and the terminal voltage is zero or nearly so.

When the unidirectional e. m. f. applied to the brushes 53, 54 is of such magnitude as to produce a flux of exactly the same magnitude and direction as that normally produced by the combined efforts of stator and rotor, then all magnetizing currents in stator and rotor will be eliminated. Under these conditions, the stator carries load currents only and these have line frequency, while the rotor carries load currents of slip frequency and a unidirectional exciting current. If the unidirectional excitation is not sufficient, the stator and rotor magnetizing currents are not entirely eliminated. If it is excessive, the machine takes leading

currents, for the reason that in order to balance the terminal e. m. f., it is necessary to dispose of a flux of a given magnitude. The motor current will so adjust itself as to keep said flux constant as long as the terminal e. m. f. remains constant. If the unidirectional magnetization under the conditions named does not produce all of the required flux, then the motor will take enough lagging current to make up the difference, while leading currents will be absorbed if it becomes necessary to reduce the magnetization produced by the unidirectional excitation.

The brushes 53, 54 can readily be revolved at synchronous speed by means of a synchronous motor geared to the brush rocker arm 105.

The unidirectional e. m. f. required for the compensation of the machine can be derived from any convenient source, but Fig. 59 shows one way of deriving said e. m. f. from the motor itself. If the inducing winding 52 is given the form of a commuted winding and brushes

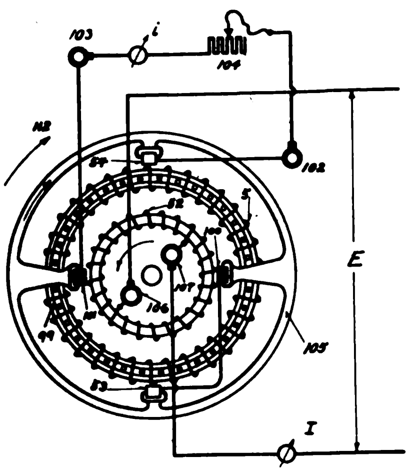

Fig. 60—Single-Phase Shunt Induction Squirrel-Cage Motor with Unidirectional Excitation (Stationary Induced Member)

100, 101 are arranged to properly cooperate with same, then a unidirectional e. m. f. can be derived from said winding 52 and utilized to produce the desired unidirectional magnetization in the rotor. When the brushes 53, 54 revolve, the unidirectional flux they locate revolves with them, and as far as the inducing winding 52 is concerned, it is as if the brushes 53, 54 were stationary and the winding 52 were rotated in a counter-clockwise direction. Under the last named conditions, it would be possible to collect a unidirectional e. m. f. preferably at the neutral points of the winding 52. These neutral points are at right angles to the axis of the field which is coaxial with 53, 54 and the brushes 100, 101 are therefore in the most suitable position to collect said unidirectional e. m. f. The conditions are not changed if the generator brushes 100, 101 and the compensating brushes 53, 54 are revolved without change in their relative positions, instead of revolving the winding 52, and if they are revolved in synchronism with the supply, nothing but a unidirectional e. m. f. will appear at the brushes 100, 101.

In Fig. 60 is shown a motor of the same type as that illustrated in Fig. 59, but in this case, the inducing member 52 revolves, while the induced member provided with a squirrel-cage winding 99 is stationary. The inducing member is provided with slip rings 106, 107 and it is assumed that it rotates in a counter-clockwise direction. With the inducing winding revolving at synchronism, the resultant motor magnetization would be stationary in space; with the rotor running below synchronism, the axis of the resultant magnetization revolves with slip frequency in a clockwise direction, thus the difference in speed between the inducing member and the revolving flux axis is always equal to the synchronous. In order to apply the phase compensating means of Fig. 59, it is only necessary to provide the stator with a commuted winding, dispose compensating brushes 53, 54 on same and revolve said brushes at slip frequency in a direction opposed to the direction of rotation of the rotor. The compensating brushes can be so revolved, for instance, by means of a differential gearing; in which case, they can be carried by the pinion of said differential, while one wheel thereof is driven from the revolving inducing winding and the other wheel is driven from a synchronous motor operated from the supply.

It will be noticed that Fig. 60 has all the elements of a single-phase converter. With the rotor 52 revolving at synchronous speed, stationary brushes, such as 100, 101, when located at right angles to the unidirectional excitation of the converter, determined by the axis of the brushes 53, 54, would be in a position to collect a unidirectional e. m. f. from the winding 52. These brushes will continue to collect such an e. m. f. as long as the difference in speed between said brushes and the winding 52 remains equal to the synchronous and as long as the brushes named are at an angle to the unidirectional magnetization produced in the machine. These conditions are readily secured in the motor of Fig. 60 by fixing the generator brushes 100, 101 in quadrature relation to the compensating brushes 53, 54 and revolving both sets of brushes at slip frequency in a direction opposed to that in which the inducing member rotates. In this way, it is possible to derive the unidirectional compensating e. m. f. from the motor itself.

12. Controlling the Phase Difference in Single-Phase Motors with Series Characteristic

Although most single-phase motors with series characteristic can be built to operate with a power factor near unity at super-synchronous speeds, yet it is sometimes very desirable to operate such machines with a power factor near unity at sub-synchronous speeds, or to run them with a leading power factor

at sub-synchronous or super-synchronous speeds. In order to achieve such results, it is necessary to resort to some method of controlling their phase difference. A number of methods are available over and above the use of condensers, which for the purpose named, can for instance, be connected in parallel with the field winding of the motor.

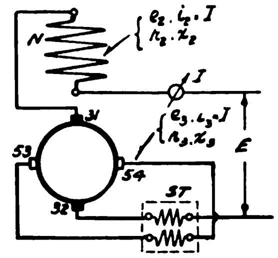

Fig. 61—Neutralized Series Motor With Two Inductively Related Rotor Circuits

One of the practical methods for controlling the power factor of a single-phase series conduction motor, in which at least part of the exciting winding is disposed on the revolving member, is to produce an auxiliary flux along the armature axis and to so select the phase thereof that the e. m. f. generated by rotation of the rotor exciting winding in said flux, opposes the reactance e. m. fs. in the motor circuit.

In order to explain the manner in which this method of phase compensation operates, an ordinary neutralized, series, conduction motor will first be considered. Such a machine is shown in Fig. 61 and the fact that a type has been illustrated in which the field circuit is disposed on the rotor, will in no way alter the conclusions to be reached. Fig. 62 is a phase diagram

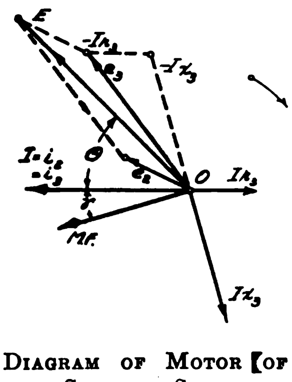

Fig. 62—Phase Diagram of Motor of Fig. 61 When Standing Still

which shows the conditions as they exist when the motor of Fig. 61 is at rest; in which case it is, of course, nothing but a choke coil. It is assumed that the transformation ratio of the series transformer S T is 1:1; so that the exciting current i_3 is practically equal in magnitude to the working current i_2, which, in this case, is the same as the line current I. The working e. m. f. e_2 at the terminals of the armature circuit will lead the armature current by a certain angle as shown, because this e. m. f. must equal and oppose the ohmic drop and the reactance e. m. f. in the armature circuit. The vectors $i_2 r_2$ and $i_2 x_2$ are not shown. When the armature current flows through the exciting winding along the axis 53, 54 of the rotor, it produces the motor field M F. Because this motor field closes through iron, it will lag by a small angle γ behind the exciting current as shown in Fig. 62. This field will produce a very large reactance e. m. f. $I x_3$ and the resistance of the field winding will cause the ohmic drop $I r_3$. The e. m. f. e_3 at the terminals of the field circuit must equal and oppose the two last named e. m. fs. and the terminal e. m. f. E must equal the vectorial sum of e_2 and e_3. Because of the unavoidably large reactance of the field circuit, the phase difference between the terminal e. m. f. and the motor current will be large.

As soon as the motor of Fig. 61 revolves at a speed s, the conditions change as indicated in Fig. 63. In this figure, the vector O E represents standstill conditions identical with those of Fig. 62. If the speed

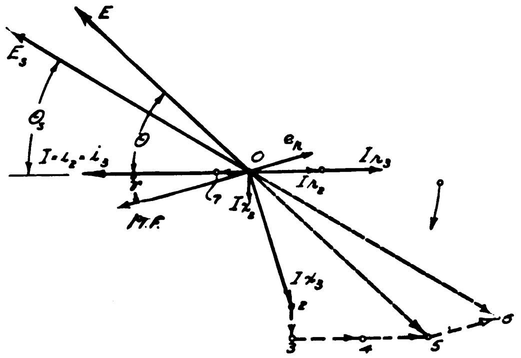

Fig. 63—Phase Diagram of Motor of Fig. 61 When Running

s is secured without any change in the motor current I, then all the vectors of Fig. 62 remain as at standstill, but due to the rotation of the rotor conductors in the motor field, an e. m. f. e_r is generated, the phase of which opposes that of the motor field and causes a reduction in the phase difference between the terminal e. m. f. and the motor current, as is plainly shown in Fig. 63, wherein E_s is the terminal e. m. f. required at the speed s. The greater improvement in the power factor of these motors is, however, brought about by the fact that with increasing speed, the current, and therefore the motor field, diminish, thus causing a diminution of the reactance voltage of the field winding. The effect of the speed e. m. f. e_r, however, immediately indicates how the power factor of such a machine can be increased independently of any change in the motor current. The problem would indeed be solved if it were possible to introduce into the circuit of the motor a speed e. m. f. of a phase substantially opposite to that of the reactance e. m. fs.

In a series conduction motor in which the field winding is located on the stator, no speed e. m. f. other than the back e. m. f. can be produced. When the

field winding, or a part of it, is transferred to the rotor as shown in Fig. 61, then a speed e. m. f. will appear at the brushes 53, 54, being due to the rotation of the rotor conductors in the leakage field along the axis 31, 32 produced by the armature ampere turns and represented by the vector *07* of Fig. 63. For the conditions as illustrated by Fig. 63, this speed e. m. f. would coincide in phase with the flux to which it is due and would, therefore, be coaxial with the vector *07*; it is not shown in the figure. It is evident that this small e. m. f. does not help matters.

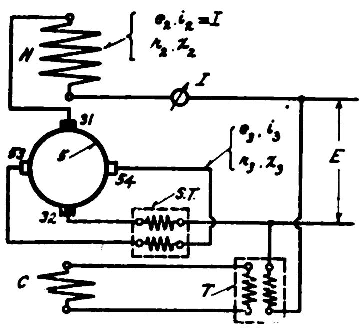

FIG. 64—COMPENSATED AND NEUTRALIZED SERIES MOTOR WITH TWO INDUCTIVELY RELATED CIRCUITS

One way of practically utilizing the suggestion contained in Fig. 63 is shown in Fig. 64. Since the rotor winding along the axis 31, 32 is neutralized by means of the stator winding N, it is clearly possible, without disturbing the conditions within the armature circuit terminals, to produce any kind of auxiliary alternating field in that axis. But if such a field is produced while at least part of the field winding is disposed on the rotor along the axis 53, 54, then a speed e. m. f. will appear along that axis and the phase thereof will be controlled by the phase of the auxiliary alternating field. The magnitude of this speed e. m. f. will depend on the speed of rotation and on the magnitude of the auxiliary field. In Fig. 64, this auxiliary field is produced by means of the stator winding C which is connected to the terminals of the motor, in other words, to the single-phase supply, by means of the shunt transformer T if desired. Under these conditions, the auxiliary field will lag by practically 90 degrees behind the terminal e. m. f. and the speed e. m. f. e_r' will be of same phase as this auxiliary field F'. After the addition of the auxiliary field F' and for an unchanged motor current the phase diagram of Fig. 63 will be transformed into that of Fig. 65, from which it is seen that the compensating speed e. m. f. e_r' is able to bring the terminal voltage and the motor current very near to phase coincidence, notwithstanding the unchanged and large reactance e. m. f. of the exciting circuit. In this diagram, the vector *08* represents the small speed e. m. f. at the brushes 53, 54, due to rotation in the armature leakage field *07*.

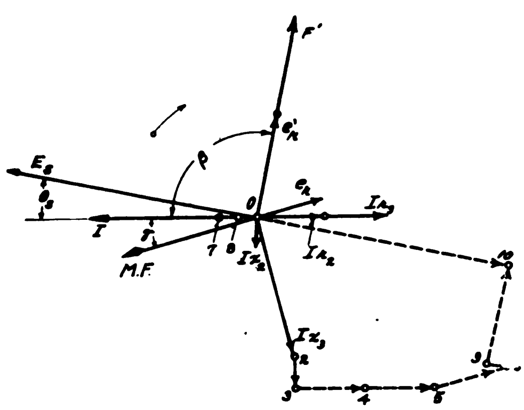

FIG. 65—PHASE DIAGRAM OF THE MOTOR OF FIG. 64 WHEN RUNNING

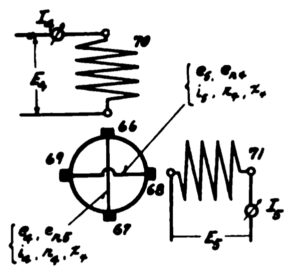

FIG. 66—TWO-PHASE SHUNT INDUCTION COMMUTATOR MOTOR

But the auxiliary flux F' produced by the stator winding C is at right angles in space to the current axis 53, 54 of the rotor, and although the current in that axis does duty as exciting current, it, nevertheless, may react with the auxiliary flux F' and may give rise to a torque. When the phase difference β between the exciting current i_3 and the auxiliary flux F' is 90 degrees, then the torque in question is zero. When β is smaller than 90, this torque is negative and opposes that produced by the interaction of the motor field $M\,F$ and the armature current i_2. When β is larger than 90 degrees, then the auxiliary torque is positive and adds to the power of the motor.

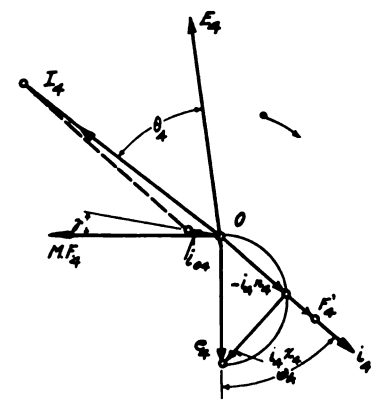

FIG. 67—PHASE DIAGRAM ALONG AXIS 66, 67 OF MOTOR OF FIG. 66 WHEN STANDING STILL

13. Methods of Controlling the Phase Difference in Asynchronous Polyphase Motors

There are polyphase motors with, and without, commutators. The commutator motors are of the induction or conduction type. Such commutator motors of the induction type as have been used in practise all have a shunt characteristic, but some of the conduction machines which have been employed

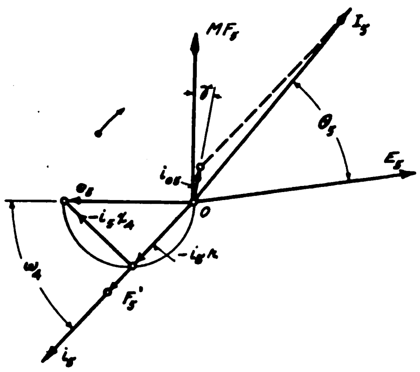

Fig. 68—Phase Diagram Along Axis 68, 69 of Motor of Fig. 66 When Standing Still

have a shunt, while others have a series, characteristic. Commutatorless motors of the induction type all have a shunt characteristic. The inherent characteristic of the polyphase induction type of motor without commutator may, however, be modified to a compound or to a series characteristic by combination with a commutator machine.

In approaching the subject of phase compensation in polyphase motors, reference will first be made to the shunt, induction, commutator motor, the two-phase form of which, is illustrated in Fig. 66.

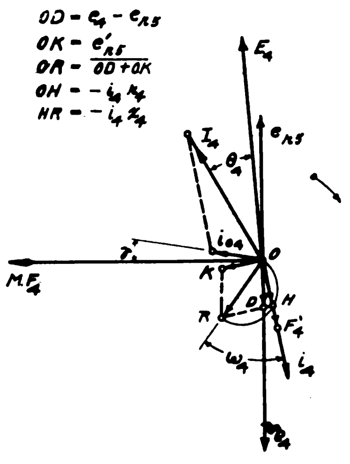

Fig. 69—Phase Diagram Along Axis 66, 67 of Motor of Fig. 66 When Running

With the rotor at rest, this machine behaves just like a short-circuited transformer. The phase diagram for the axis 66, 67 is shown in Fig. 67, that for the axis 68, 69 in Fig. 68. These diagrams are self-explanatory and show that because of the time constant of the rotor, the secondary currents i_4 and i_5, which are the rotor working currents, lag very considerably behind the corresponding rotor working e. m. fs. e_4 and e_5, with the result that the currents in the primaries 70 and 71 also lag considerably behind the respective terminal e. m. fs. E_4 and E_5.

What happens when the rotor is released and allowed to reach its normal and slightly sub-synchronous speed is shown in Figs. 69 and 70 which are the phase diagrams for the axes 66, 67 and 68, 69 respectively. The rotation of the rotor adds two speed e. m. fs. to the active elements in each rotor axis. Thus, in the axis 66, 67 appears the e. m. f. e_{r5}, which is the back e. m. f. in that axis, and is due to rotation of the rotor conductors in the transformer flux produced by the stator 71. The other speed e. m. f. in this axis is e_{5r}' represented by the vector OK of Fig. 69 and due to the rotation of the rotor conductors in the leakage flux set up by the ampere turns due to the rotor current i_5

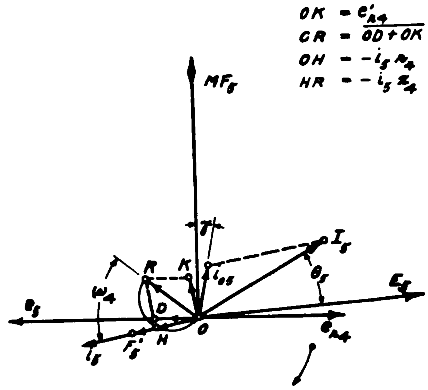

Fig. 70—Phase Diagram Along Axis 68, 69 of Motor of Fig. 66 When Running

circulating along the axis 68, 69. A back e. m. f. e_{r4} generated by rotation in the transformer flux due to the stator phase winding 70 and the additional speed e. m. f. e_{r4}' due to rotation in the rotor leakage flux set up along the axis 66, 67 are added to the rotor circuit 68, 69.

The resultant in each axis between working and back e. m. f. is represented by the vector $O\,D$ which, in combination with the speed e. m. f. $O\,K$, yields the effective e. m. f. $O\,R$ in each rotor axis. Because the time constant of the rotor remains unchanged, the rotor currents must lag behind the effective rotor e. m. fs. by the same angle, regardless of speed, and are shown so lagging in Figs. 69 and 70. Notwithstanding the fact that the time constant of the rotor does not change, it is seen that, when up to speed, the working currents i_4 and i_5 are very nearly in phase with the corresponding working e. m. fs. e_4 and e_5. This is entirely due to the speed e. m. fs. represented by the vectors $O\,K$. One peculiarity of these e. m. fs. is that at synchronism, their magnitude is such as to entirely compensate for the rotor reactance e. m. f. and to

bring the rotor current into exact phase coincidence with the rotor working e. m. fs. These "self-compensating" e. m. fs. vary with the speed. At sub-synchronous speeds, they are smaller than the rotor reactance e. m. fs. At super-synchronous speeds, they exceed the latter.

14. Controlling the Phase Difference in Polyphase Induction Motors with Shunt Characteristic by Introducing into the Armature Circuits e. m. fs. Opposed in Phase to the Rotor Reactance e. m. fs.

a. A study of Fig. 66 and of the four diagrams relating to it at once shows that it is a simple matter to control the phase difference in that machine by amplifying the self-compensating feature of that motor, or in other words, by injecting into the axis 66, 67 an e. m. f. of about same phase as e_{r5}'; and into the axis 68, 69 another e. m. f. of approximately the same phase as that of e_{r4}'. Since the former is about opposite in phase to the terminal e. m. f. E_5 and the latter of about the same phase as the terminal e. m. f. E_4, it is only necessary to provide the arrangement shown in Fig. 71 in order to compensate the motor of Fig. 66 to any desired extent. In Fig. 71, an e. m. f. derived from the stator along the axis 68, 69 is conductively introduced into the rotor circuit at right angles to said axis, while an e. m. f. derived from the stator along the axis 66, 67 is conductively introduced into the rotor axis 68, 69 at right angles to 66, 67.

This method of phase control corresponds to one of the methods described in connection with single-phase motors. In the case of polyphase machines, it is very simple to apply because a polyphase supply is available. It, however, suffers from the disadvantage of increasing the resistance of the working circuits and of adding reactance thereto, thus lowering the efficiency of the motor and making it necessary to inject compensating e. m. fs. of sufficient magnitude to take care of internal, as well as external, reactance. External reactance can, of course, not be taken care of by any self-compensating feature and therefore requires changes in the magnitude of the external compensating e. m. fs., if the power factor is to be kept constant while the load varies. By referring to Figs. 69 and 70, it will be seen that any phase relation within reason can be secured between working e. m. fs. and currents by changing the magnitude of the compensating e. m. f. $O\,K$; and that the rotor working currents can be made to lead to a degree sufficient to compensate for the magnetizing component of the stator windings.

It is not possible to influence the phase relations within a motor of the type shown in Fig. 66 by changing the phase of the exciting e. m. fs. or the phase of the motor fields, and this is for the reason that there is an interdependence and reciprocity between the several axes of such a machine. Thus, the transformer flux produced by the stator winding 70 not only conveys the energy to the rotor or armature along the axis 66, 67, but also does duty as motor field for the currents induced in the rotor axis 68, 69, by the transformer field due to the stator winding 71; which field, in turn, acts as motor field to the currents induced in the rotor along the axis 66, 67. The phase of the rotor working e. m. f. in the axis 66, 67 and the phase of the rotor back e. m. f. in the axis 68, 69, both depend on the phase of the transformer flux set up by the stator winding 70. Similarly, the phase of the working e. m. f. in the rotor axis 68, 69 and the phase of the back e. m. f. in the axis 66, 67 both depend on the phase of the transformer flux produced by the stator winding 71. If the phase of one of the transformer fluxes is changed, the phase relations of working and back e. m. fs. in both axes will be changed, improving the power factor

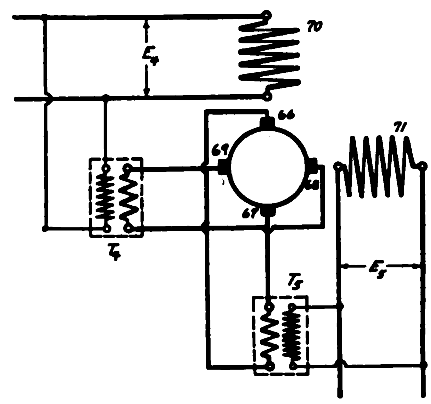

Fig. 71—Compensated Two-Phase Shunt Induction Commutator Motor

in one axis and making it worse in the other. If the phase of both transformer fluxes is altered to the same extent, none of the phase relations within the motor will be changed. Not only does a polyphase induction motor differ from the corresponding single-phase by machine in this matter of reciprocity, but it also differs by the fact that in the single-phase machine, armature and field circuits are both on the induced member; whereas in the polyphase motor, the induced member, generally the rotor, carries nothing but working currents, the motor field being produced by means of the stator or inducing windings.

Polyphase motors of the induction type, but without commutators, can be compensated just as described in connection with Fig. 71, provided care is taken to supply to the induced member e. m. fs. of proper periodicity. In the case of Fig. 71 the brush current periodicity is, at all speeds, the same as that of the stator or of the line, hence the possibility of using the static transformers T_4 and T_5 for deriving the compensating e. m. fs. In the case of a polyphase induction motor with slip rings, the periodicity of the rotor currents as they appear at the slip rings changes with the slip of the machine, being zero at synchronism and increasing proportionately with the slip. The periodicity of the com-

pensating e. m. fs. must vary in the same manner and the phase of each of these e. m. fs. must lead the phase of the corresponding current, or rather that of the corresponding working e. m. f. by about 90 degrees. A number of devices satisfying these conditions were invented soon after it was found that polyphase motors had come to stay and some of these are referred to hereinafter.

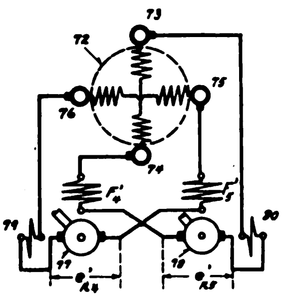

Fig. 72—Polyphase Shunt Induction Slip-Ring Motor With a Plurality of Compensating Series Generators in the Induced Circuit

b. The arrangement shown in Fig. 72 is one of the earliest which were proposed. It is illustrated as applied to a polyphase motor, the induced member 72 of which carries a two-phase winding. Here, as in most of the other cases, a two-phase arrangement has been selected as permitting of clearer illustration. The inducing member is not shown. One of the rotor phases is connected to the slip rings 73, 74 the other to the slip rings 75, 76 and these slip rings are connected to two alternating-current commutator generators driven in any desired manner. Each rotor phase is connected in series with the exciting winding of one generator and the armature of the other. The armature reaction in each generator is neutralized by means of the windings 79 and 80 respectively. The current in the rotor phase 73, 74 produces the exciting flux F_4' of one of the generators. This flux is in phase with the current in the rotor phase 73, 74. By rotation of the generator armature 77 in the flux F_4', an e. m. f. is generated at the brushes of said armature which is always of same phase and same periodicity as the current in 73, 74, and the magnitude of which depends on that of F_4', and on the speed of rotation of the generator armature 77. This e. m. f. e_{r4}' is, therefore, in phase quadrature with the current in the rotor phase 75, 76; and if injected into that rotor circuit in the proper direction, it will oppose the reactance e. m. fs. in that circuit. Similarly, the e. m. f. e_{r5}' generated in the armature 78 by rotation in the flux F_5' of same phase as the current in 75, 76, is in phase quadrature with the current through 73, 74 and is available for compensating purposes in that rotor phase. In fact, the exciting fluxes of the two generators can be compared to the leakage fluxes in the two axes of the rotor of Fig. 66; and the e. m. fs. generated in the armatures 77 and 78 are comparable to the speed e. m. fs. represented by the vectors $O K$ of Figs. 69 and 70, with this difference, that while the speed e. m. fs. in Fig. 66 are of constant frequency, the frequency of the corresponding e. m. fs. in Fig. 72 varies with that of the currents in the rotor of the motor to be compensated and therefore with the slip of said rotor.

Whereas the compensating arrangement of Fig. 71 permits of the power factor to be brought to unity at no load, as well as under any load condition, that illustrated in Fig. 72 does not allow material raising of the power factor at no load, or at light loads, without unduly over-compensating the machine under full-load. The reason for this is that the currents in the rotor 72 vary approximately in proportion with the load, whereas a compensating e. m. f. of nearly constant magnitude is sufficient to ensure a practically constant power factor from no load to full load. The type of compensation shown in Fig. 71 may be termed "shunt" while that shown in Fig. 72 may be spoken of as "series" compensation.

While the sources from which the compensating e. m. fs. are derived in Fig. 72 are not devoid of reactance, yet the arrangement clearly indicates possibilities of materially reducing this reactance as compared with the magnitude of the compensating e. m.fs. which can be generated. Since the periodicity of the compensating e. m. fs. is independent of the speed of the generators 77, 78, these can be operated at high speeds and the exciting fluxes can be kept small, thus reducing the principal source of reactance in these generators. For the same reason, very few armature turns can be used, the desired magnitude of compensating e. m. f. being secured by running the armatures at a correspondingly higher speed. The neutralizing windings 79, 80 further help to reduce the reactance of these compensators.

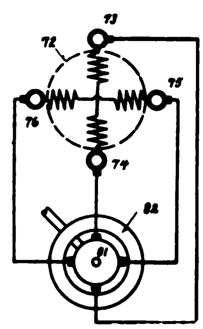

Fig. 73—Polyphase Shunt Induction Slip-Ring Motor With One Compensating Series Generator in the Induced Circuit

c. A simpler and better compensating arrangement for shunt induction motors of the slip-ring type is shown in Fig. 73, where a single compensating generator of the series type is used for all the rotor phases. The stator of the motor to be compensated is not shown; the rotor is again indicated at 72 and is provided with a two-phase winding. One of the phases is connected to the slip rings 73, 74, the other to the slip rings 75,76

The stator of the compensating generator consists of laminations, but carries no winding. The two-pole armature is provided with two sets of brushes displaced by 90 electrical degrees from each other. One phase of the rotor 72 is carried to one set, the other to the other set of these generator brushes. Any suitable provision is made for rotating the generator armature 81 at the desired speed. With the armature 81 at rest and connected to the rotor 72, a revolving field will be produced in the armature and will rotate with the slip frequency of the motor to be compensated. Under these conditions, the armature 81 will exhibit a positive reactance, will, in other words, act like a choke coil. If this armature be now revolved in the direction of the revolving field produced by the rotor currents and at the same speed as this field, then there will be no relative motion between the conductors of the armature 81 and the revolving field and the armature will act as an ohmic resistance. Should the speed of this armature be now increased without changing its direction of rotation, then it will exhibit the properties of a condenser, generating e. m. fs. in advance of the currents circulating through it. These leading e. m. fs. are generated by rotation in the field produced by the rotor currents; their magnitude can

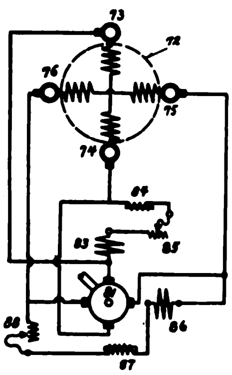

Fig. 74—Polyphase Shunt Induction Slip-Ring Motor With One Compensating Shunt Generator in the Induced Circuit

be raised to any desired degree by raising the speed of the armature 81. Independently of this speed, the periodicity of the leading e. m. fs. will always be the same as the periodicity of the currents circulating through the armature 81. Here, then, is a device with a very small inherent positive reactance capable of generating a compensating e. m. f. greatly in excess of said reactance as to magnitude; for this reason, it is well suited to the service to which it is put.

The stationary laminations 82 can be eliminated, but this would reduce the magnitude of the flux for a given number of ampere turns on the armature 81. It is further possible to combine the stator 82 with the armature 81, partly or entirely eliminating the air gap between the two and cause both of them to revolve in unison.

This device, like the previous one, does not allow of adequate compensation at no-load and the compensation to be secured at light loads is also limited. The power factor can, however, be increased at the light loads without adversely affecting the phase relations under full-load by saturating a part of the magnetic circuit, say for instance, that between the slots in which the winding on the armature 81 is located. In this way, the flux, due to the current circulating in the compensator will not increase in proportion with said current and a greater compensating effect at light loads may automatically be secured without overcompensating at full load. Of course, if complicated regulating arrangements are permitted, then all of these compensators with series characteristic can be made to approach more closely to the performance of compensators with shunt characteristic, but it is not thought that such devices are of practical value. As an indication of their nature, it may be stated that in a device where the laminations 82 are stationary, greater constancy of power factor can be secured by moving the armature 81 out of the stator 82 with increasing load.

d. Series compensating devices fail to produce a high power factor at no-load because of lack of excitation of the compensator when the slip of the motor to be influenced is small. An attempt was made at least partly to overcome this difficulty, and while the writer has no definite data on this subject, he believes that Fig. 74 correctly represents the device in question. It differs from that shown in Fig. 73 in that the stator is provided with two exciting windings 83, 86. One of these exciting windings is located in line with one of the brush sets, the other is coaxial with the second pair of brushes. The winding 83 is connected in parallel with the brushes to which it is coaxial and the same is true of the winding 86. The e. m. f. appearing at each set of brushes co-operating with the armature 81 is, therefore, impressed on the exciting winding coaxial with that set. The object of the arrangement is to produce at each pair of brushes an e. m. f. which will lead the current through that set of brushes by about 90 degrees. Under these conditions and because the flux produced by a shunt exciting winding lags by practically 90 degrees behind the e. m. f. impressed on its terminals, the flux due to the exciting winding 83 will be substantially in phase with the armature current in the vertical axis and therefore substantially in phase quadrature with the current in the horizontal armature axis of the compensator, or vice versa. For this reason, the e. m. f. of rotation appearing at the horizontal set of brushes will be in quadrature with the current through these brushes and the same is true of the vertical set. Because at no-load the slip and the rotor e. m. fs. and currents are small, it is not easy to secure sufficient excitation of the compensator, even with the arrangement of Fig. 72, but acceptable results can be had. The fluxes set up by the currents in the armature

81 induce e. m. fs. in the windings 83 and 86 and rotation of the armature conductors in said fluxes also generates e. m. fs. The former disturb, the latter help compensation and greatly exceed the former if the armature speed is high. Furthermore, the phase relation between terminal e. m. f. and flux varies in the exciting windings 83, 86 with varying slip frequency and this necessitates adjustment of the im-

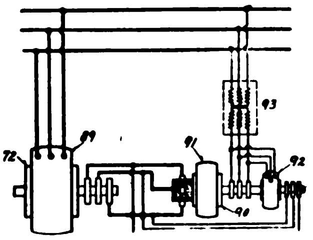

Fig. 75—Polyphase Shunt Induction Slip-Ring Motor With a Compensating Frequency Converter in the Induced Circuit

pedance of these circuits. The easiest way to accomplish this is with the help of adjustable reactances 84, 87 and adjustable resistances 85, 88. The adjustment is so made as to secure e. m. fs., the compensating components of which are nearly constant at all loads. This arrangement is consequently apt to influence the speed, as well as the power factor of the machine. The armature reaction of 81 could be neutralized with advantage.

e. A more perfect method of controlling the phase differences in a polyphase slip ring motor at no-load, as well as at any load, is shown in Fig. 75, where a suitably driven frequency converter is connected between the slip rings of the motor to be regulated and the polyphase line. The frequency converter is nothing but a three-phase synchronous converter provided with a polyphase arrangement of brushes on the commutator instead of the usual direct current brush gear. In the example shown in Fig. 75. the induced member 72 of the motor to be regulated is provided with three slip rings. In consequence, the commutator of the converter 90, 91 is provided with a three-phase arrangement of brushes on its commutator. The slip rings of this converter are connected to the polyphase line by means of the three-phase step-up transformer 93, this being necessary because of the necessarily low voltage of the induced member 72. The stationary member 91 of the converter usually carries nothing but commutating windings.

When the main motor 72, 89 operates near synchronism, the frequency of its rotor currents is very low; it is always proportional to the slip of the rotor. Any compensating e. m. f. introduced into the rotor under these conditions must have the same low frequency and in order to derive this low frequency e. m. f. from the line, the converter 90, 91 is used. When the rotor of such a converter is at rest, then the frequency at the stationary commutator brushes is the same as the frequency at the slip rings. Line frequency being impressed on the slip rings of the converter 91. a revolving flux will be set up in the machine rotating with line frequency and thus accounting for the line frequency voltage at the stationary commutator brushes. The phase relation between any commutator brush voltage and any slip-ring voltage can be varied in the simplest manner by displacing the brushes on the commutator. The voltage between commutator brushes will, however, remain constant for all brush positions. If the rotor 90 of the converter is rotated in a direction opposed to that in which the revolving field produced by the slip-ring currents revolves, then the frequency of the commutator brush voltage will diminish, for the reason that the speed of revolution of the revolving fluxes with respect to the stationary commutator brushes will have diminished. When the speed of the converter reaches the synchronous, the flux produced by the slip-ring currents will be stationary in space, will have no relative motion with respect to the commutator brushes and the e. m. f. at said brushes will be unidirectional. It is thus seen that in order to derive from the converter 90, 91 e. m. fs. of same frequency as the currents in the rotor 72 of the motor to be regulated, it is only necessary to drive the converter in synchronism with the rotor 72. This can be done mechanically by suitably gearing the converter armature 90 to the motor armature 72, or it can be done electrically, for instance, as shown in Fig. 75. Here, a small three-phase motor 92 is arranged to drive the converter. The primary of this auxiliary motor is connected to the line in any desired manner, while the secondary is connected in parallel to the rotor 72. The connections are so made that

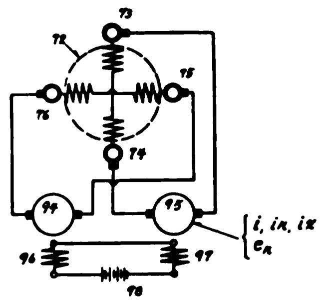

Fig. 76—Polyphase Shunt Induction Slip-Ring Motor With Compensating Oscillators in the Induced Circuit

an increase of frequency in the rotor 72 because of a sub-synchronous speed will cause the auxiliary motor 92 to run at a correspondingly lower speed, while an increase in this rotor frequency, because of a super-synchronous speed of the main rotor 72, will raise the speed of the auxiliary motor by a corresponding amount. The phase of the e. m. fs. derived from the commutator end of the converter can be adjusted by displacing the commutator brushes, or by displacing the stator of the auxiliary motor 92, or by changing the phase of the e. m. fs. impressed on the converter

slip rings. The copper and iron losses of the converter are supplied by the transformer 93, the friction losses by the auxiliary motor 92; and the latter therefore, need only be small. The commutator of the converter must handle the heavy currents of the rotor 72 at a varying, but fortunately, a low frequency, unless this arrangement is also made use of for speed regulation, when the frequencies of the commutator currents will, of course, increase in proportion to the range of speed regulation.

f. Another not so perfect, but very interesting method of controlling the phase difference in a polyphase motor is shown in Fig. 76. It consists in including in each phase of the induced member a direct current armature free to oscillate in a unidirectional

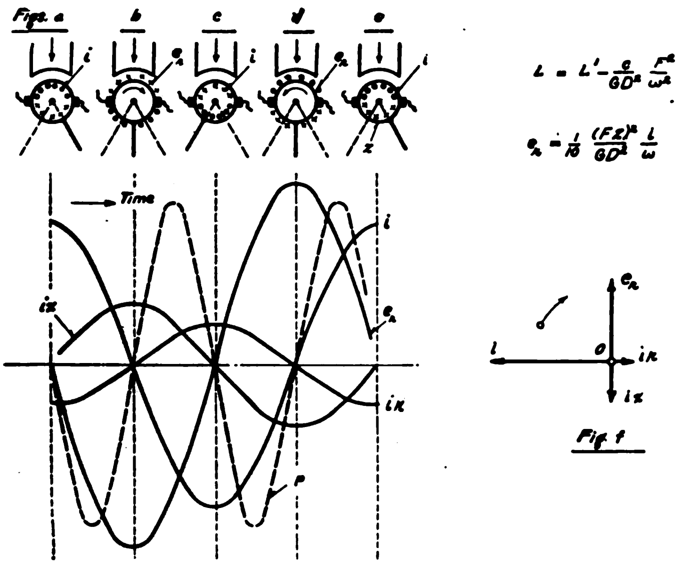

FIG. 77—PHASE RELATIONS IN OPERATING RECUPERATOR, OR VIBRATOR, OR OSCILLATOR

field. These oscillating generators have been referred to as "recuperators" and also as "vibrators." Because of the somewhat unusual type of this apparatus a little space may, advantageously, be devoted to its fuller discussion.

In Fig. 76, the stator of the motor to be controlled is not shown and its rotor 72 is supposed to be provided with a two-phase winding, one of these phases being connected to the slip rings 73, 74, while the other is connected to the slip rings 75, 76. The first phase is closed through the direct-current armature 95, the second through the direct-current armature 94. Each of these armatures is of the usual construction and has a commutator with which cooperate brushes stationary in space. Each of these armatures is so mounted as to reduce friction to a minimum and each is placed in a unidirectional field excited by the field windings 96, 97 connected to a storage battery 98 or to a similar source of unidirectional e. m. f.

The currents in the rotor 72 are alternating, and near synchronism, their frequency is low. The question is, how will an armature such as 94 or 95 behave when an alternating current of low frequency is sent through it by way of the stationary commutator brushes? It will at once be recognized that the armature will be subject to a torque, the direction and magnitude of which, will vary, causing said armature to constantly reverse its direction of rotation. As the armature revolves in the unidirectional field F, see Fig. 77, an alternating e. m. f. e_r will be generated in the conductors of said armature. The amplitude of this e. m. f. will be zero when the speed of the armature is nil, that is, at the moment the armature reverses its direction of rotation; and it will be a maximum when the armature moves at its highest rate of speed, that is, when half-way through its travel. Since an oscillating armature cannot permanently absorb or permanently give out work, it is clear that the e. m. f. e_r must have a phase displacement of 90 degrees with respect to the current i circulating through the oscillating armature, which means that this current will be a maximum whenever the armature is at rest and zero whenever it passes through its intermediate position. For the reasons just stated, and as may be seen from Figs. 77a, 77b, 77c, 77d, and 77e, the e. m. f. e_r will lead the current i and the phase relations will be as shown in Fig. 77 and Fig. 77f. Starting with the armature at rest in the extreme right hand position shown in Fig. 77a, and assuming that the armature current i, which is then at its maximum, flows in a positive direction, this current will decrease as the armature moves in a clockwise direction and will be zero when it is in its intermediate position as shown in Fig. 77b. In Fig. 77a, the speed of the armature is zero, in Fig. 77b, it is a maximum; and the e. m. f. generated by a clockwise rotation of the armature reaches a negative maximum for the position shown in Fig. 77b, declining to zero while the armature goes through the second half of its clockwise motion. The direction of the current reverses when the armature is in the position of Fig. 77b, grows in intensity as the armature goes through the second half of its clockwise motion and reaches a negative maximum when it reaches its extreme left hand position shown in Fig. 77c. The armature now moves in a counterclockwise direction to the position shown in Fig. 77d, during which time, the current diminishes from its negative maximum to zero, while the e. m. f. e_r rises from zero to its positive maximum and so forth. The armature must be accelerated as it goes from the position shown in Fig. 77a, to that of Fig. 77b, and retarded as it moves from the latter to the position shown in Fig. 77c. It must, therefore, absorb work during the first, and give out work during the second, period just named, as indicated by the dotted line P of Fig. 77. Because of the impedance of the armature, there will be an ohmic drop $i\,r$ of opposite phase to i and a reactance e. m. f. $i\,x$ lagging by 90 degrees behind i and it is necessary to so select the constants of the apparatus as to make e_r consider-

ably larger than $i\,x$ if any phase compensation is to be achieved.

If the oscillator is so constructed that it is devoid of elastic reactions and that any damping effects produced are negligible as compared to the moment of inertia $G\,D^2$, then the coefficient of self-induction of the apparatus as a whole can be written in the form of a difference between the coefficient of self-induction of the movable armature winding and a term which is proportional to a constant depending on constructive features of the apparatus, and to the square of the unidirectional flux F and is inversely proportional to the moment of inertia of the armature and the square of the current frequency.

$$\angle = \angle' - \frac{c}{GD^2} \cdot \frac{F^2}{\omega^2}$$

No compensating effect can be produced unless the second member of this equation is made larger than the first. This can be done by making the oscillating element as light as possible and of a very small diameter by using a large unidirectional flux and by reducing the frequency of the current through the armature, thus reducing the angular speed corresponding to the frequency.

Some compensators of this type have been built, and Prof. G. Kapp has given the following formula for e_r

$$e_r = \frac{1}{10} \quad \frac{(F\,Z)^2}{G\,D^2} \quad \frac{i}{\omega}$$

where Z is the number of active conductors on the oscillating armature and ω is the angular speed corresponding to slip frequency. It is interesting to note that because i does not vary with the load as fast as ω, the effect of the compensator is relatively greater at low loads; but this is no drawback, for the reason that the greater compensation is required at the lower load. Nevertheless, it is not possible with this arrangement to secure any appreciable compensation at no-load. Because of the low frequency of the currents circulating through the commutator, and further because at maximum speed of the armature the current is zero, commutation is very good.

15. Controlling the Phase Difference in Polyphase Induction Motors with Shunt Characteristics by Injecting a Unidirectional E. M. F. into the Induced Member

a. In Fig. 78 is shown a three-phase squirrel-cage motor in which the stationary member 109 is the inducing one and is connected to the three-phase supply in the ordinary way. When connected to the supply the stator produces a flux of practically constant magnitude revolving in synchronism with the periodicity of the supply. In normal operation, the squirrel-cage rotor revolves in the same direction as the field produced by the stator and nearly at the same speed as the latter. In order to compensate this machine with the help of a unidirectional e. m. f., and without destroying its asynchronous characteristics, it is only necessary to provide the rotor with an additional, but commuted winding, provide brushes to co-operate with the commutator, rotate these brushes in synchronism with, and in the same direction as, the revolving field produced by the stator and arrange to have the brush axis

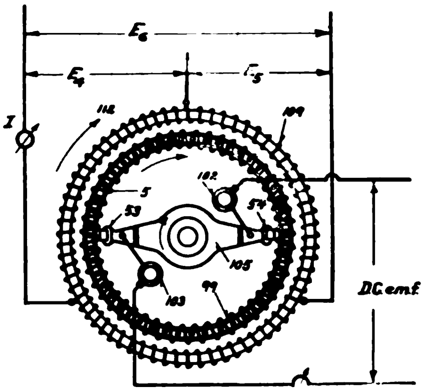

Fig. 78—Polyphase Shunt Induction Squirrel-Cage Motor With Unidirectional Excitation (Stationary Inducing Member)

always coincide with the axis of the revolving field. In this way, it is possible to produce, by means of a unidirectional current sent into the commuted winding of the rotor, a unidirectional flux which will, at every instant, be coaxial with the revolving flux produced by the stator. If the direction and magnitude of the flux

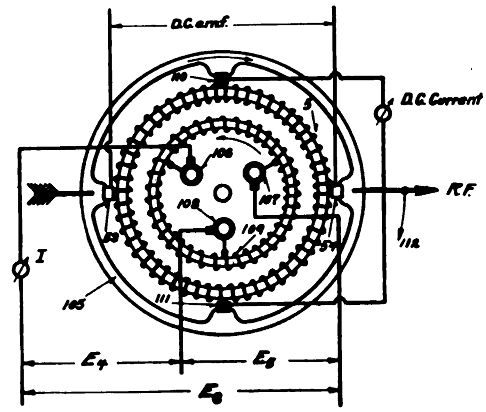

Fig. 79—Polyphase Shunt Induction Motor With Unidirectional Exciting and Load Currents in the Induced Member (Stationary Inducing Member)

produced by the direct current are equal to the direction and magnitude of the flux normally produced by the stator, then all magnetizing currents in the latter will disappear. If the magnitude of the unidirectional flux is increased, then the stator will take leading currents so as to produce a magnetization opposed to the unidirectional one and thus reduce the total magnetization of the motor to that required to balance the terminal e. m. fs. The e. m. f. to be impressed on the compensating brushes can be derived from any desired

unidirectional source. It can, for instance, be taken from the motor itself, as has been explained in connection with Figs. 59 and 60.

If the inducing member of Fig. 78 is caused to revolve while the induced member is held stationary, then the compensating brushes must be revolved at slip speed in a direction opposed to that in which the inducing member rotates.

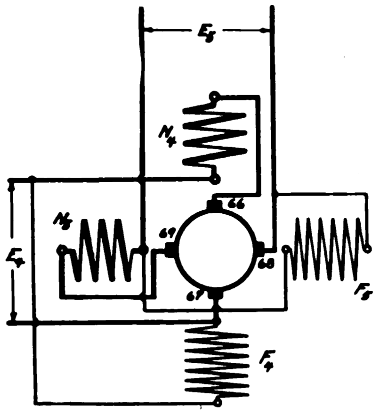

Fig. 80—Neutralized Two-Phase Shunt Conduction Motor

b. There is another type of polyphase induction motor which has not as yet been used in practise, but which is of considerable theoretical interest and also lends itself to the type of phase compensation described in connection with Fig. 78.

This machine is shown in Fig. 79 in the form in which the inducing member is adapted to revolve,

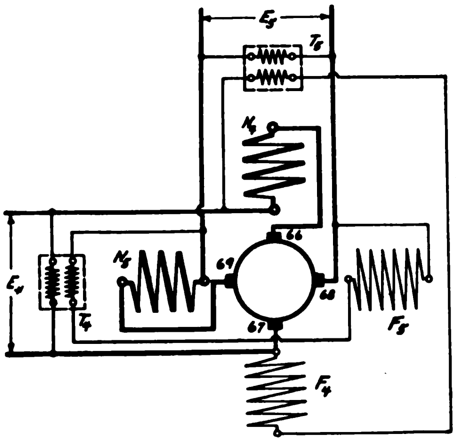

Fig. 81—Neutralized and Compensated Two-Phase Shunt Conduction Motor

while the induced member is stationary. The inducing member is provided with a three-phase winding connected to the slip rings 106, 107, 108 in the ordinary way, while the induced member carries a commuted winding with which cooperate the short-circuited brushes 110, 111. Assume that the slip rings are connected to the supply and that the alternating currents circulating in the inducing member produce a flux $R\ F$ of nearly constant magnitude revolving in a clockwise direction. If the inducing member is now rotated at synchronous speed in a counterclockwise direction, the flux produced by it will become stationary in space and its axis may, for instance, be horizontal as indicated in the figure. Under these conditions, no e. m. fs. will be induced in the windings on the secondary member and if we dispose short-circuited brushes such as 110, 111 along an axis displaced by 90 electrical degrees from the axis of the flux produced by the inducing member, no current will circulate through these brushes and the motor will not be in a position to develop any torque. But if the speed of the inducing member falls below the synchronous, then the axis of the field produced by the inducing member will begin to revolve in a clockwise direction, as indicated by the arrow 112, and at a speed equal to the slip of the inducing member, for the relative speed between the inducing member and the axis of the revolving flux produced by it, must at all times be equal to the synchronous. As soon as the axis of this flux begins to revolve, e. m. fs. are generated in the commuted winding on the induced member and a current flows through the short circuit produced by the brushes 110, 111. If these brushes remain stationary in space, the current circulating through them will have slip frequency, but if they are rotated at slip frequency in a clockwise direction, that is, in synchronism with the flux produced by the inducing member and preferably in such position as to be always at right angles to the axis of said flux, then the short-circuit current will be unidirectional. The short-circuited brushes 110, 111 can be revolved in the desired manner by driving them through a differential gearing, the brushes being driven by the pinion of this gearing, while one of the gear wheels is connected to the shaft of the inducing member and the other to the shaft of a synchronous motor operated from the supply. Such a machine behaves in every respect like an ordinary squirrel-cage polyphase induction motor except that the current in the rotor short-circuit is unidirectional.

In order to compensate this machine, it is only necessary to dispose on the rotor compensating brushes 53, 54 displaced by 90 electrical degrees with respect to the working brushes 110, 111, revolve said brushes in synchronism with the working brushes and impress on them a unidirectional e. m. f. of proper magnitude and direction. Since the working brushes are located and revolve in an axis displaced by 90 electrical degrees with respect to the axis of the revolving field of the machine, the axis of the compensating brush will coincide with the axis of said revolving field, and any flux produced by a unidirectional current entering and leaving the commuted winding on the stator by means of the compensating brushes will affect the magnitude or direction, or the magnitude and direction, of the magnetizing currents circulating in the inducing member and thus modify the power factor of the machine.

In case the inducing member is stationary and the induced member free to revolve, then the system of working and compensating brushes co-operating with the commuted winding on the induced member must be made to revolve at synchronous speed and in the direction in which the induced member revolves.

The unidirectional compensating e. m. f. can be derived from the motor itself by making use of its converter characteristics as has heretofore been set forth with reference to Figs. 59 and 60.

16. CONTROLLING THE PHASE DIFFERENCE IN POLYPHASE CONDUCTION MOTORS WITH SHUNT CHARACTERISTIC BY CHANGING THE PHASE OF THE EXCITING E. M. FS.

The neutralized, polyphase, shunt, conduction motor the two-phase form of which, is shown in Fig. 80, is one which can be compensated by changing the phase of its exciting e. m. fs.

The e. m. f. E_4 of one phase is impressed on the armature circuit comprising the rotor along the axis 66, 67, and the coaxially disposed neutralized winding N_4. This same e. m. f. is impressed on the exciting winding F_4 coaxial with N_4. Similarly, the e. m. f. E_5 of the other phase is impressed on the rotor along the axis 68, 69 in series with the neutralizing winding N_5 and also on the exciting winding F_5 coaxial with N_5. Because the flux due to F_4 lags by about 90 degrees behind E_4 it is of same phase as E_5 or of same phase as the current through the rotor axis 68, 69 when the latter is in phase with its terminal e. m. f. For the same reasons, the flux due to F_5 is in phase with the armature current along the axis 66, 67 when the current is in phase with E_4. In this machine, the motor fluxes F_4 and F_5 are entirely independent of the working circuits and their phase and magnitude can be regulated at will without affecting anything but the torque per ampere and the corresponding back e. m. fs. Consequently, the phase of these back e. m. fs. can be so set as to produce any desired phase relation between the rotor or armature currents and the corresponding terminal e. m. fs., simply by changing the phase of the exciting fluxes. This can be most readily done as shown in Fig. 81. Here, two e. m. fs. are impressed on each of the exciting windings. All of E_4 and such part of E_5 as is determined by the shunt transformer T_5, is impressed on F_4. Similarly, all of E_5 and such part of E_4 as is determined by the shunt transformer T_4, is impressed on F_5. By varying the voltages delivered by the two shunt transformers, it is possible to control the power factor of the motor over an extremely wide range.

Phase compensation produced by modifying the phase of the exciting e. m. f. in single-phase or polyphase motors always yields the best results, and does not require any adjustments in order to obtain a substantially constant power factor from no-load to full-load, or even beyond. The compensating e. m. f. is injected in a highly inductive circuit in which the current is practically constant; and the source of this e. m. f. may be highly inductive without exerting any detrimental effect on the constancy of the power factor.

An attempt has been made to refer to all compensating methods of theoretical interest or of practical value, yet it was not intended to do more than deal with the theories involved and there was no intention to discuss the various applications of these methods. If any method of importance has been omitted, it is due to inadvertence and the author will be glad if his attention is called to it so that this record may be completed.

Most of the compensating methods can, with slight changes, also be used for regulating the speed of alternating-current motors. In fact, the motor speed is often affected by phase control, simply for the reason that a slight change in the phase of the compensating e. m. f. will often bring about a change in speed. Thus, in the case of polyphase induction motors, the e.m. fs. injected into the rotor will do nothing more than compensate the motor as long as they are in phase quadrature with the working e. m. fs. Should this quadrature relation be disturbed, then the speed of the motor will be affected to a degree depending on such disturbance, for it will be remembered that an e. m. f. of the same phase as a working e. m. f. and of the same or opposite direction, will either raise the rotor speed above, or depress it below, the synchronous. When the injected e. m. fs. are not in phase quadrature with the working e. m. f., each is bound to have a speed-changing component.

AIRPLANE RADIO COMMUNICATION

Experiments on the use of radio apparatus as an aid in aerial navigation are described in a publication recently completed. The experiments were conducted jointly by the Post Office Department and the Bureau of Standards and have resulted in the following conclusions:

Radio signaling is a practical aid to navigation provided certain precautions are taken, such as making the radio apparatus sufficiently rigid to stand severe vibration and the use of a special type of antenna located in the fuselage of the machine as far as possible from the engine and the wires of the ignition system. Metal sheaths must be provided to protect the radio receiving apparatus from the ignition system, though the disturbances from this cause can be reduced by the use of a compensating coil in the receiving apparatus.

The use of a coil type of antenna or radio compass makes it possible not only to carry on communication but also to guide the airplane and determine its position by radio methods. By the use of special transmitting apparatus located on the landing field, the airplane is able to determine its position with respect to the field and to descend safely in darkness or fog. Two methods have been found practicable for such signaling apparatus; the use of alternating current of relative low frequency in a large coil on the landing field, and the use of radio signals transmitted from a special type of antenna on the landing field.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

AKRON-CLEVELAND MEETING
JANUARY 14, 1921

On Friday, January 14, 1921, the American Institute of Electrical Engineers will hold its 366th meeting under the auspices of the Cleveland and Akron Sections and the Industrial and Domestic Power Sub-committee on the Rubber Industry.

During the morning of the 14th, Institute headquarters will be at the rooms of the Akron Engineering Society, where the Board of Directors and scheduled committees will meet. At 12:30 p. m. luncheon will be served in the cafeteria of the B. F. Goodrich Plant at Akron. An inspection trip through the plant will immediately follow and continue until about 4 p. m. Special cars will leave the plant for Cleveland at about 4:30 p. m. on the Interurban, arriving at about 6:30 p. m.; when a dinner will be served at Hotel Statler ($3.00 per plate). The evening technical session will be held in the rooms of the Cleveland Engineering Society at 8:15 p. m., and will be devoted to the presentation of a paper on "Applications of Electric Power in the Rubber Industry" under the joint authorship of the members of the Subcommittee on Rubber Industry of the Industrial and Domestic Power Committee.

Institute members from the East may obtain through sleepers from New York to Akron, leaving Pennsylvania Station at 6:50 p. m. daily, arriving at Akron at 9:00 a. m. Special cars will leave Cleveland for Akron at 10:00 a. m. from the Interurban Station.

Program

9:30 a. m. Board of Directors
Akron Engineering Society Rooms, 80 South Main Street

9:30 a. m. Scheduled Committee Meetings
a. Akron Engineering Society Rooms, 80 South Main Street
b. Northern Ohio Traction and Light Company Offices, Terminal Building. Akron.
(Hour and place of each meeting will be given in notices to members of committees scheduled to meet.)

12:30 p. m. Cafeteria Luncheon.
B. F. Goodrich Company Plant, South Main Street, Akron.

1:30 p. m. Inspection Trip.
B. F. Goodrich Plant.

6:30 p. m. Dinner (Informal).
Hotel Statler.

8:15 p. m. Technical session.
Cleveland Engineering Society Rooms, 14th Floor, Hotel Statler.
Paper on *Application of Electric Power in the Rubber Industry*, by the Sub-committee on the Rubber Industry.

A. I. E. E. MIDWINTER CONVENTION FEBRUARY 16-18, 1921

The seventh Midwinter Convention of the A. I. E. E. will be held in New York City, February 16-18, in the United Engineering Societies Building.

The Convention will include six technical sessions; visits to various power plants; a dinner dance; and the Edison Medal presentation, followed by a lecture.

Wednesday morning will be devoted to the registration of members and guests in attendance, and making arrangements for visits to the different power plants in New York City and the vicinity, which will be made on Wednesday afternoon. On Wednesday evening there will be a technical session. Thursday morning and Thursday afternoon will also be devoted to technical sessions, and on Thursday evening the usual Midwinter Convention Dinner Dance will be held at the Hotel Astor. There will be technical sessions on Friday morning and Friday afternoon, and the Convention will close with the Friday evening session, at which the Edison Medal will be presented to Dr. M. I. Pupin, as noted elsewhere in this issue. The presentation of the medal will be followed by a lecture, the subject of which will be announced later.

The tentative program is as follows:

PROGRAM

Wednesday Morning, Feb. 16th

Registration Office open.

Wednesday Afternoon

Inspection of local electrical plants.

Wednesday Evening

Opening address by the President.
Results of Questionnaire on Oil Circuit Breakers for the Protective Devices Committee, by H. R. Woodrow.
Tests on Oil Circuit Breakers, by P. Torchio.
Moving pictures and oscillograph records of switches at the instant of failure.

Thursday Morning, Feb. 17th

Sub-committee on Wires and Cables, Standards Committee.
Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low, by W. A. Del Mar, *Chairman*, P. Torchio, D. W. Roper, W. S. Clark, R. W. Atkinson, L. L. Elden.

Thursday Afternoon

Telephone and Telegraph Committee, D. McNicoll, Chairman.
Multiple Use of Wires, by S. Rhoads.
Carrier Wave Telephony, by F. B. Jewett and B. Gherardi.

Thursday Evening

Dinner Dance at the Hotel Astor.

Friday Morning, Feb. 18th

Instruments and Measurements Committee

F. V. Magalhaes, Chairman.

A New Design of Current Transformer, by H. B. Brooks and F. C. Holtz.

Regulation of Frequency for Purposes of Measurements, by P. H. Smith.

A New Type of Differential Voltmeter, by E. D. Doyle.

Variation of Eddy Currents in Conductors of Different Stranding, by J. A. Cooke.

Mechanical Wave Analyser, by F. S. Dellenbaugh.

Stopwatches, by A. L. Ellis.

Friday Afternoon

MISCELLANEOUS SESSION

Short-Circuit Current of Induction Motors and Generators, by R. E. Doherty and E. T. Williamson.

Hysteresis Phenomena with Superimposed Frequencies, by W. Fondiller.

The Longitudinal Flow of Heat in the Windings of Electrical Machinery, by C. J. Fechheimer.

Friday Evening

EDISON MEDAL PRESENTATION

Lecture on Recent Advances in Science.

FUTURE SECTION MEETINGS

Chicago.—January 24, 1921. Subject: "Research, A National Issue and How to Meet it in a Practical Way."

February 28, 1921. Subject: "Dependence of Aerial Transport on Electricity."

Pittsfield.—January 20. 1921. Subject: "On the Frontiers of the Universe, or an Evening with the Stars." Speaker: Mr. B. R. Baumgardt, Lecturer. Los Angeles and New York.

Portland, Ore.—February 7, 1921. Subject: "Public Utility Financing." Speaker: Mr. Geo. Meyers.

Vancouver.—January 17, 1921. Subject: "Electrical Energy Rates." Speaker Mr. E. E. Walker.

NEW YORK SECTION MEETING IN DECEMBER

A joint meeting of the New York Section of the American Institute of Electrical Engineers, the Management and Metropolitan Sections of the American Society of Mechanical Engineers and the Taylor Society was held in the Engineering Societies Building, December 3, 1920.

President Fred J. Miller of the A. S. M. E. presided, and after some introductory remarks presented Mr. Horace B. Drury, recently with the Industrial Relations Division of the U. S. Shipping Board, who presented a paper on "The Three-Shift System in the Steel Industry." The discussion which followed was opened by Robert B. Wolf, Consulting Engineer of New York, and was also participated in by Messrs. William H. Baldwin, formerly secretary of the Ohio Steel Company; S. P. Rectanus, Director of Employment, American Rolling Mill Company; J. A. McCleary, Secretary, Iron and Steel Institute; Harrington Emerson, Consulting Engineer, New York; Whiting Williams, recently Vice-President of the Hydraulic Pressed Steel Company; J. H. Willitts, University of Pennsylvania.

SUPER-POWER SURVEY

In his annual report to the President, the Secretary of the Interior has briefly reported the progress that is being made by William S. Murray and his corps of consultants in the status of the work that has been accomplished to date. It is interesting to note that the Secretary is confident that the report will deserve public confidence. This opinion seems to be borne out in industrial and financial opinions already expressed. The report of the Secretary of the Interior follows:

"Congress at its last session placed upon this department the duty of making a special investigation of the possible economy in fuel, labor, and material that could be secured by electrification of the railroads and industries of the region between Boston and Washington. The plan contemplated is a unified system of power generation and power distribution, and its investigation has been called the super-power survey. This is now under way. The engineering profession and large business interests are giving this project support that is at once an indorsement and a promise of public confidence. The engineering staff engaged in this intensive study of the power needs and the means of meeting that demand includes men who have done pioneer work in applying electricity to the use of man; while serving on an advisory board are men of vision and experience, representing our larger railroads as well as electric railways, our manufacturing and mining industries, and the engineering and chemical profession, busy men who have accepted my invitation to help direct this investigation along lines of greatest practical usefulness. Every industry that has to do with either making power or using power is giving generous cooperation.

"The area being studied, while only a small fraction of the United States—2 per cent—uses 24 per cent of the electric output of the central stations of the country and produces about 47 per cent of its manufactured products. It is properly termed the finishing shop of American industry. The report of this investigation will be completed June 30 next, and its purpose is to give an engineering solution to the problem of the demand of the nation for greater production and better transportation. That answer is electrification, but its details must include the accurate statement of costs in capital and of savings in coal and labor. I believe the report will deserve public confidence."

AMPERE CENTENARY CELEBRATED AT THE CROCKER-WHEELER WORKS

A formal celebration of the electrical discoveries of Ampere was held at the works of the Crocker-Wheeler Company on the afternoon of December 4th. A large number of electrical engineers was present and a special train was provided to take the guests from New York City.

Dr. Schuyler S. Wheeler, President of the Company, acted as Chairman and after some introductory remarks introduced Prince de Béarn, of the French Embassy, of Washington, who gave a brief account of Ampère's accomplishments. Dr. M. I. Pupin was the next speaker and he gave a very interesting story of the intimate details of Ampère's life. The speaking was concluded by Dr. C. O. Mailloux, who represented the French Academy of Science on this occasion, and who read a paper on the subject of fundamental electrical research.

Following the speeches a light luncheon was served, after which the party adjourned to the railway station, where a tablet in honor of Ampère had been erected in 1908. At the celebration last month Prince de Béarn unveiled a bronze wreath with suitable inscription which is to be placed above the tablet in commemoration of this centenary celebration.

EDISON MEDAL AWARDED TO DR. M. I. PUPIN

On December 8, the Edison Medal Committee of the American Institute of Electrical Engineers awarded the Edison Medal for the year 1920 to Dr. M. I. Pupin, "for work in mathematical physics and its application to the electrical transmission of intelligence." Arrangements will be made for the presentation of the medal to Dr. Pupin at a session of the midwinter convention of the Institute in New York on Friday evening, February 18, 1921.

The Edison Medal was founded by the Edison Medal Asso-

ciation, composed of associates and friends of Mr. Thomas A. Edison, and is awarded annually by a committee consisting of twenty-four members of the American Institute of Electrical Engineers "for meritorious achievement in electrical science, electrical engineering, or the electrical arts."

Michael Idvorsky Pupin was born in 1858 in Idvor, Banat, Hungary now forming part of the Kingdom of the Serbs, Croatians and Slovians.

After completing his education at the village school and showing unusual talents he was sent to Prague, Czecho-Slovakia, to continue his education in studies preparatory for higher education. He ran away from Prague and came to America; landed in New York in 1874, and after five years struggle for existence saved up enough money to enter Columbia College, where he graduated with high honors in 1883, with a B. A. degree.

He then went to Europe for the purpose of taking up graduate work in physics and mathematics at the University of Cambridge, England, and at the University of Berlin, Germany and after taking a Ph. D. at Berlin returned to Columbia University where, together with Professor F. B. Crocker, he started in 1889 the Electrical Engineering Department as instructor in mathematical physics. His principal study in Berlin was physical-chemistry, but owing to the fact that physical-chemistry at that time was a new science at the universities in the United States it was not possible to continue his researches in this science at Columbia and he turned his attension to researches in electrical science.

Dr. Pupin's earliest work was devoted to the study of the passage of electricity through rarefied gases and several papers concerning the results were published. In 1892 he took up the subject of electrical resonance, which resulted in the invention of the employment of tuned circuits for selective electrical reception of signals. The expression "electrical tuning" was invented by him at that time and is used in the art today. Also resonance analysis by tuned circuits was worked out by him, employing for means of selectivity by tuning, circuits of variable inductance and variable capacity. The inventions resulting were acquired by the American Marconi Wireless Company in 1902.

In 1895-6 he developed a method of rectifying both low and high frequency oscillations so as to make them detectable by d-c. instruments. The rectifier consisted of a polarized electrolytic cell, and it was clear to him at that time that rectification was a very important element in wireless telegraphy, an opinion which has been wonderfully justified by the developments in the wireless art which have taken place within the last twenty-five years.

The subject of electrical wave transmission over long conductors began to occupy Dr. Pupin's attention as early as 1894, and his earliest work in this direction was chiefly mathematical, and it resulted in an extension of the great problem of La-Grange, namely, the problem of analyzing the motion of a stretched weightless string carrying at equal intervals of its length equal masses. Pupin extended the solution of this problem by supposing that the string itself had weight and that both the string and the masses moved against frictional resistance, taking into consideration not only the free vibrations of the string but also the forced motion produced in it by impressing upon it a simple harmonic force. The solution of this purely dynamical problem suggested immediately its applicability to transmission of electrical waves over telephone wires and it was obvious that the introduction of suitable inductance coils at pre-determined distances along the telephone line would greatly improve the efficiency of transmission by making it possible to transmit the electrical energy carrying the articulate voice of man by high potential and small current, thus reducing ohmic resistance losses on the line. The invention was acquired by the American Tel. & Tel. Co. in January 1901, after this company had convinced itself that the invention was capable of performing those things which the theory had claimed for it. The practical applicability of this invention required the knowledge of making highly efficient inductance coils, using iron cores very finely laminated, and Pupin devoted a study of several years to the investigation of these iron losses, resulting in the design of the toroidal coil, known all over the world as the Pupin coil.

During the war Dr. Pupin served on several national committees connected with war work, particularly the National Advisory Committee for Aeronautics and the National Research Council, and with a Government committee for submarine detection, which had its headquarters at New London. Pupin and his staff were engaged in developing a method of submarine detection by means of very high-frequency sound waves sent out by a panel of vibrating quartz plates. Since the wave length of these sound waves in water was small in comparison with the dimensions of the vibrating plate, the sound waves were concentrated in a beam similar to the light beam sent out by a searchlight. The detection consisted in receiving an echo from a submerged submarine, and it is the only means which enables one to detect submarines which are at rest determining not only the direction but also the distance of the submarine. In prosecuting this work Dr. Pupin developed a multi-step vacuum tube amplifier which is free from internal noises and which does not transmit low frequency under-water noises. This work is now in charge of the United States Navy.

Pupin's work in wireless telegraphy has always occupied his attention, being interrupted now and then by other scientific engagements due to his connection with several national committees. The results of this work were recently acquired by the Westinghouse Company. The principal feature in this work is the so-called negative resistance compensator, which according to competent opinion is destined to play a very important part in the wireless art.

Professor Pupin is a member of the National Academy of Sciences, of the National Research Council, of the Serbian Academy of Sciences, and of many other learned societies, and has been a Fellow of the American Institute of Electrical Engineers for many years. He has received from the French Academy the Herbert Prize in Physics, and from the Franklin Institute the Carson Gold Medal, also the Gold Medal from the Social Science Association. He also holds honorary degree of Doctor of Science, Columbia University, and the honorary degree of Doctor of Laws of Johns Hopkins University. He is now Professor of Electro-Mechanics, Columbia University, and is Director of the Phoenix Research Laboratory of the same university.

ENGINEERS CLUB OF BALTIMORE

The Engineers Club of Baltimore, whose present quarters are at 6 West Eager Street, have made arrangements for new quarters in the Merchants and Manufacturers Building, effective about the first of the year. The new quarters are commodius and will provide, in addition to a lounge and recreation room, an assembly hall with seating capacity of 500, club office. committee rooms for the Club and its affiliated societies and a very comprehensive technical library, on which the Club proposes to spend at least $1,000. per year.

The membership of the Club is being increased rapidly in order to take care of the expansion, and at the meeting of the Campaign Committee, held November 26th, a total of 228 members was reported, or a gain of 100 members in one week, in addition to the societies, which have affiliated with the Engineers Club, aggregating 1000 affiliated members. The affiliation of various other technical societies with the Engineers Club affords such societies facilities of the Club and the use of the assembly hall one night per month. The local sections of the following are now affiliated with the Engineers Club:

American Society of Mechanical Engineers.

American Society of Civil Engineers.
American Institute of Electrical Engineers.
American Association of Engineers.
American Chemical Society

The dues for the Club have purposely been held down as it is desirous to secure as many young members as possible in order to perpetuate the Club and insure a continually increasing sphere of influence.

The dues for full membership are $25.00 per year; Non-resident, $10.00 per year; Associate $25.00 per year; Junior $10.00 per year; Student $5.00 per year.

The advantages offered to members of the Engineers Club are manifold among which are: The opportunity for engineers and technical men to act as a unit; to participate in civic affairs; to meet each other under pleasing surroundings (the centrally located Club Rooms which will be open day and night); access to a technical library and other club facilities and a complete acquaintance in the profession.

The development of Baltimore as a seaport and an industrial center involves a multitude of engineering problems and it is the desire of the Engineers Club to participate to the fullest extent possible in this development.

Application blanks for membership may be obtained from Mr. Wm. F. Strouse, Chief Engineer, Public Service Commission Chairman of Membership Committee; from Geo. S. Robertson 109 East Redwood St., Secretary of the Club, or from any member of the Club.

NOMINATION AND ELECTION OF INSTITUTE OFFICERS FOR 1921-1922

As provided in Section 19 of the Institute By-Laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1921, by the petition or by the separate endorsement in writing, of not less than twenty-five members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1921. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: a President and a Treasurer for the term of one year each, ten Vice-Presidents for the term of two years each, and three Managers for the term of four years each.

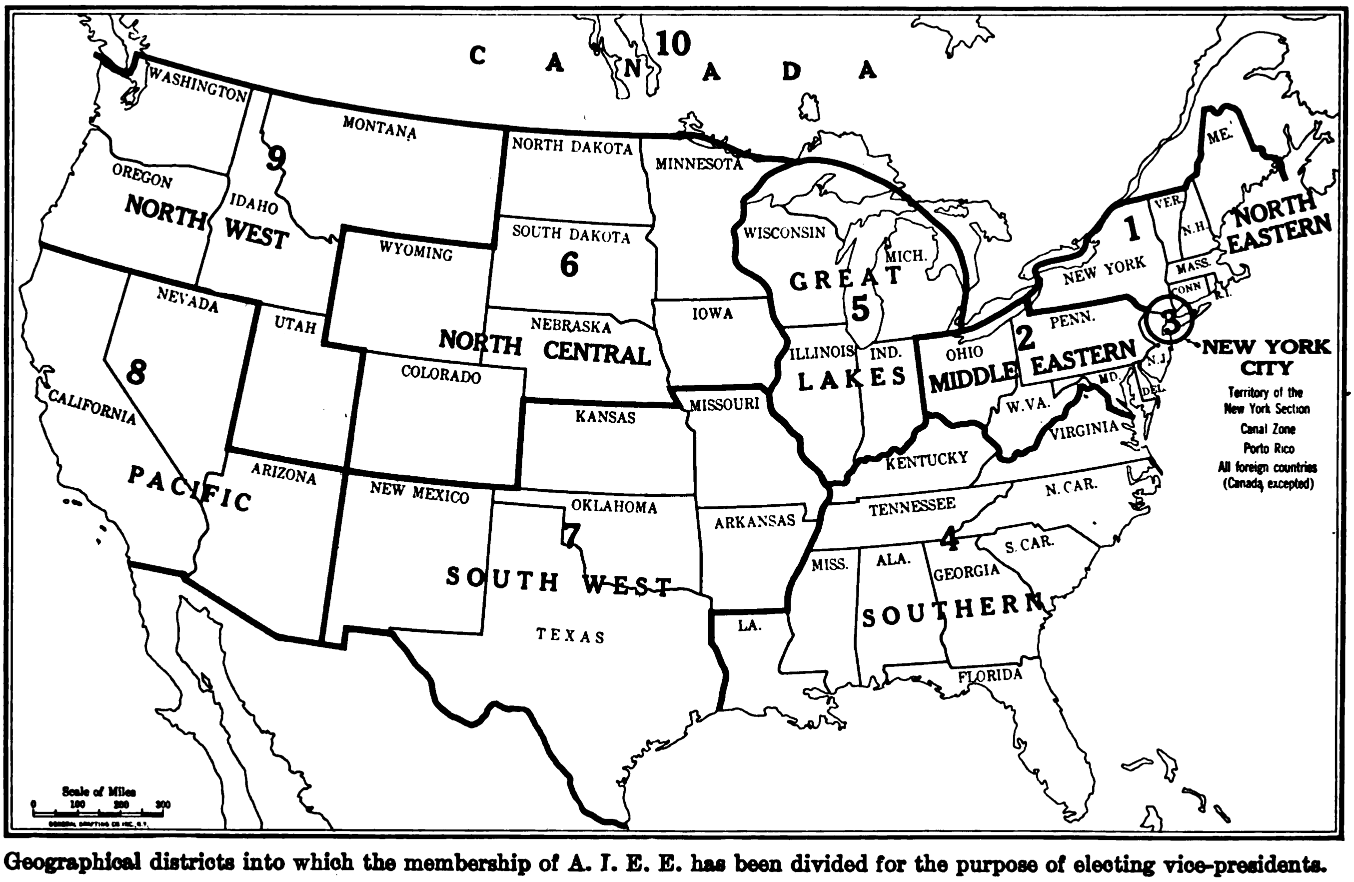
At the Annual Meeting of May 1920, amendments to the Constitution were adopted, carrying out the recommendations of the Committee on Development, in its report of August 12, 1919, that the membership be grouped into geographical districts, that one Vice-President be elected from each district and that Vice-Presidents hold office for a term of two years. The recommendation for the removal of the constitutional inhibition upon the election of a Vice-President as Manager was complied with and the immediate re-election of a Vice-President to the same office provided for with provision against too extended term of office. The former inhibition upon the re-election of a President or Manager to the same office was continued.

At the November 12 meeting of the Directors revisions of the By-Laws were adopted, including the definition of the ten geographical districts decided upon by the Committee on Geographical Divisions and Election Procedure. The ten districts defined in Section 21 of the By-Laws are, as follows:

1. North Eastern: Connecticut (exclusive of N. Y. Section territory), Maine, Massachusetts, New Hampshire, New York (exclusive of N. Y. Section territory), Rhode Island, Vermont.

2. Middle Eastern: Delaware, District of Columbia, Maryland, New Jersey (exclusive of N. Y. Section territory), Ohio, Pennsylvania, West Virginia.

3. New York City: Territory of the New York Section, Canal Zone, Porto Rico, all foreign countries (Canada excepted).



Geographical districts into which the membership of A. I. E. E. has been divided for the purpose of electing vice-presidents.

4. Southern: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia.

5. Great Lakes: Illinois, Indiana, Michigan, Wisconsin.

6. North Central: Colorado, Iowa, Minnesota, Nebraska, North Dakota, South Dakota, Wyoming.

7. South West: Arkansas, Kansas, Missouri, New Mexico, Oklahoma, Texas.

8. Pacific: Arizona, California, Nevada, Haw'aii, Philippines.

9. North West: Idaho, Montana, Oregon, Utah, Washington, Alaska.

10. Canada:

According to the revised Constitution one Vice-President must be elected from each geographical district but this does not debar members in one district. is they so wish, from nominating and voting for a candidate in another district. When the votes are counted the cadidate for Vice-President having the largest vote in each district will be elected to that particular office for that district, irrespective of the fact that he may have polled a smaller number of votes than a man standing second in another district.

For the information of members the full text of revised sections of the Constitution and By-Laws applying to Officers, nominations, elections, etc.. are printed below:

CONSTITUTION

Sec 23. The officers of the Institute shall be a President, one Vice-President from each geographical district as defined in the By-Laws, twelve Managers, a Secretary and a Treasurer.

Sec. 24. The President, the Secretary and the Treasurer shall hold office for one year, the Vice-Presidents for two years and the Managers for four years. The President and Managers shall not be eligible for immediate re-election to the same office. No Vice-President or Manager who has served continuously in one or more offices, and whose combined terms shall have aggregated six years or more, shall be eligible for immediate election to the office of Manager or Vice-President. At each Annual Meeting the President, the requisite number of Vice-Presidents to fill vacancies caused by expiration of terms, three Managers and the Treasurer shall be elected by the membership, and their terms of office shall commence on the first of August next succeeding their election. . . . . . .

Sec 24 A. At the election of Vice-Presidents held in 1921 there shall be elected one Vice-President from each geographical district, those from the odd-numbered districts to serve for one year each, and those from the even-numbered districts two years each. All Vice-Presidents elected thereafter shall serve for two years each. In the event of a change in the geographical districts, the Vice-Presidents then in office shall complete their terms. In case of revisions of the geographical districts, the Board of Directors shall have the power to elect a Vice-President from each district not represented, to serve until the next election covering these districts.

BY-LAWS

Sec. 19. In addition to the names of the incumbents of office the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May provided for in Article VI, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than twenty-five members, received by the Secretary of the Institute in writing by January twenty-fifth of each year: provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's Journal and shall be reproduced on the form above referred to.

Sec. 21. There shall be ten geographical districts grouped as follows: (For the balance of this Section describing districts see paragraph preceding map.)

Sec. 21A. Should the territory of any Institute Section lie in more than one geographical district as defined above, then the entire territory of said Section shall be considered as belonging to the geographical district in which the headquarters of the Section are located.

AMERICAN ENGINEERING STANDARDS COMMITTEE

ELECTION OF OFFICERS

At the annual meeting of the American Engineering Standards Committee held in New York on December 4th, Mr. A. A. Stevenson, a representative of the American Society for Testing Materials, was reelected Chairman for 1921, and Mr. George C. Stone, a representative of the American Institute of Mining and Metallurgical Engineers, was reelected Vice-Chairman. The following were also elected to represent the respective member-bodies on the Executive Committee:

Comfort A. Adams	American Institute of Electrical Engineers
Martin Schreiber	American Society of Civil Engineers
Fred E. Rogers	American Society of Mechanical Engineers
A. H. Moore	Electrical Manufacturers Council
Dana Pierce	Fire Protection Group
A. Cressy Morrison	Gas Group
N. A. Carle	National Electric Light Association
Albert W. Whitney	National Safety Council
Coker F. Clarkson	Society of Automotive Engineers
Thos. H. MacDonald	U. S. Department of Agriculture
E. B. Rosa	U. S. Department of Commerce
O. P. Hood	U. S. Department of Interior
Francis J. Cleary	U. S. Navy Department
J. H. Rice	U. S. War Department

A. I. E. E. SPONSOR FOR RATING OF ELECTRICAL MACHINERY

The American Institute of Electrical Engineers was designated as sponsor for the rating of electrical machinery by the American Engineering Standards Committee at its meeting on December 4th, and the responsibility for the work has already been officially accepted by the Institute. A sectional committee is being formed which will contain official representatives of the Electric Power Club, the National Electric Light Association, and the various other interested bodies, to carry out the work.

These arrangements have been made at the request of the electrical industry, in order to prepare as quickly as possible for the next meeting of the Rating Committee of the International Electrotechnical Commission, at which questions of great importance to the industry will be taken up, including the fundamental basis of rating. At the last meeting of the Rating Committee in Brussels in March, 1920, the American delegates presented a proposal for a system of rating based upon the hot-spot principle, which was tentatively adopted by the Rating Committee, and published as a recommendation to the various national bodies composing the Commission for official adoption by the Commission at its next meeting.

TERMINAL MARKINGS FOR ELECTRICAL APPARATUS

The Electric Power Club to act as Sponsor for Standardization

The Electric Power Club has been designated as sponsor for the standardization of terminal markings for electrical apparatus. A sectional committee responsible for the work, and upon which all organizations interested in the subject will be officially represented, is being organized.

At the Brussels meeting of the International Electrotechnical Commission, in March 1920, some of the European delegates proposed a method for marking terminals of transformers. The American delegates suggested that it would be preferable to treat the more general subject of terminal markings for

electrical apparatus consistently. As a result the Americans were requested to propose a systematic plan for the whole subject.

The Electric Power Club has already done a large amount of work on the subject and has developed a general plan which is in wide use among American manufacturers. Parts of the plan, particularly the part relating to transformers, have been adopted by other organizations, including the American Institute of Electrical Engineers and the National Electric Light Association.

It is hoped to secure agreement of all interested bodies, on a general plan for representation at the next meeting of the International Electrotechnical Commission.

NEW BODIES REPRESENTED

The American Engineering Standards Committee has recently been enlarged by the representatives of four additional member-bodies. These bodies and their representatives are:

U. S. Department of Agriculture
- C. L. Alsberg, Chief, Bureau of Chemistry
- Earle H. Clapp, Forest Service
- T. H. MacDonald, Chief, Bureau of Public Roads

U. S. Department of the Interior
- E. A. Holbrook, Assistant Director, Bureau of Mines
- O. P. Hood, Chief Mechanical Engineer, Bureau of Mines
- P. S. Smith, Administrative Geologist, Geological Survey

Gas Group (American Gas Association, Compressed Gas Manufacturers' Association, International Acet lene Association)
- A. H. Hall, Supt. of Distribution, Central Union Gas Co.
- A. C. Morrison, Vice-President, Compressed Gas Manufacturers Association
- H. S. Smith, President, International Acetylene Association

American Electric Railway Association
- (Official representatives not yet designated)

There are now 47 members of the Committee, representing 17 member bodies. In all, 24 organizations are represented on the Committee, as three of the member-bodies are groups of organizations.

STANDARDIZATION OF ZINC

The American Society for Testing Materials and the American Zinc Institute have accepted joint sponsorship for the standardization of zinc under the auspices and rules of procedure of the American Engineering Standards Committee.

The Association Belge de Standardisation has suggested international standardization of the following matters pertaining to zinc: grades of commercial zinc; gage thicknesses and tolerances for sheet zinc; methods of sampling and determining moisture content of ores; and methods of analysis of ore and spelter. The American committee will work along the lines of the Belgian suggestion, but the work will not be confined to these points.

The Belgian Association has suggested similar work on the other non-ferrous metals.

RULES OF PROCEDURE REVISED

As a result of a year's experience, during which progress has been made on each of about 40 standardization projects, the American Engineering Standards Committee has completely re-drafted its Rules of Procedure. Clarification in light of experience was the principal consideration in the revision, and but very few changes in substance, and those minor ones, have been made. The most important of these are explicit recognition of the representation of organizations as such in the make-up of the working ("sectional") committees, and the introduction of a greater flexibility into parts of the rules.

The American Engineering Standards Committee, generally spoken of as the Main Committee, does not concern itself with the technical details of standards. The formulation of any particular standard is in the hands of a working committee, called a *sectional committee*, which is made up of representatives designated or approved by the various bodies, technical, industrial, etc., concerned in the standard. The personnel of the sectional committee must be approved by the Main Committee as being authoritative and adequately representative of the industry, and of the various bodies concerned, producers, consumers, and general interests must be represented upon all sectional committees dealing with standards of a commercial character.

In one important particular the procedure differs from that of other national standardizing bodies. Sectional committees are organized, not by the Main Committee, but by one of the principal bodies interested, designated for the purpose by the Main Committee, and termed the *sponsor* for the particular project. A body may act as sponsor whether it is represented on the Main Committee or not, and two or more bodies may act as joint sponsors for a project.

Copies of the revised rules may be obtained by addressing a request to the American Engineering Standards Committee, 29 West 39th Street, New York City.

ENGINEERING COUNCIL

REGISTRATION OF ARCHITECTS, ENGINEERS, AND LAND SURVEYORS

A recommended uniform law for registration of architects, engineers, and land surveyors was drafted by the Committee on Licensing Engineers, and submitted with the committee's report on December 18, 1919. Council had authorized the creation of this committee on October 25, 1918, and a thorough study of the subject was made during the fourteen months that ensued before the report was completed. Council gave the report wide publicity (See JOURNAL for February, 1920, p. 188) so that others might benefit by the committee's work, and that Council might obtain criticism and experience to aid in further work.

In December, 1919, a Joint Committee of the American Institute of Architects and Engineering Council was created to consider subjects of interest to both architects and engineers. This committee, at a meeting held September 15, 1920, approved the proposition of joint registration laws, and laid down certain basic principles which such laws should contain.

Engineering Council at a meeting held October 21, 1920 adopted the report of the Committee on Licensing Engineers, in which was incorporated a final draft of the recommended uniform law, made to accord with suggestions elicited during the past year. As chairman of this committee, Mr. T. L. Condron said in part, in his letter of transmittal to Engineering Council, October 21, 1920:

I have the honor to transmit to you the attached Report which was prepared and submitted to the sixteen members of the committee on the 4th inst.

At the writer's request Mr. Shenehon, chairman of the Joint Committee and member of License Committee, came to Chicago yesterday, and he and the writer have carefully gone over the entire proposed law so to modify it as to incorporate practically all of the valuable suggestions which have come from the members of our committee and others during the past ten months.

It has also been the aim to make the proposed law satisfactory to the Board of Directors of the American Institute of Architects by incorporating those features recommended by the Joint Committee.

For your information, it is well to state that the License Committee was unanimous a year ago in feeling that the only justification for a law of this kind was as stated in Section 1: "In order to safeguard life, health and property, any person practising architecture, engineering or land surveying shall be required to submit evidence that he or she is qualified so to practise.

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In conclusion, I hand to you the proposed registration law submitted to you nearly one year ago, with some slight modifications and improve-

ments agreed upon between myself and the Chairman of the Joint Committee.

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I am sure that I express the sentiments of the majority of the Committee in recommending that Council approve and endorse the attached amended "Recommended Uniform Registration Law for Architects, Engineers and Land Surveyors" as a bill for an act of legislation in each and every State for the regulation of the practise of the professions of Architecture, Engineering and Land Surveying.

Respectfully,
T. L. CONDRON
Chairman License Committee

Francis C. Shenehon of the Joint Committee outlined briefly the purpose of the law in a letter to Engineering Council, November 4, 1920. The main part of his letter follows:

It appears desirable I think to make clear that the final draft of the Registration Law promulgated is a composite representing the views of the original committee on "licensing" and the later committee on "cooperation".

The vital thing in a law of this kind is that it shall furnish the public a reliable criterion by which an architect or engineer may be selected to plan and execute important work. A "registered" architect or engineer has in his title his credentials. A man who offers to practise or does practise, representing himself to be an architect or engineer—because in practise prior to the law—may be embarrased in explaining his status; and men of this kind will register for the prestige of it. This will further discredit those not registering because not qualified. And for persons beginning the practise of architecture or engineering after the passage of this Act, the law rigorously prohibits those not qualified under the law itself from representing themselves, either by the titles "Architect", or "Engineer" in any of its many variations, or in any other way, as architects or engineers.

A carpenter may continue to plan and build sheds, barns, garages, warehouses, dwellings or business blocks, with no implication that he is an architect. A road master may continue to build roads with earth cuts and embankments, culverts and pile or concrete bridges, with no implication that he is an engineer. A contractor may continue to plan and erect cableways, trestles, towers, cement, sheds, dinky railways, or he may plan and erect silos, elevators or office buildings for clients, and with no implication that he is an engineer. A manufacturer may continue to plan and build boilers, engines, water tanks, windmills and turbines without any implication that he is an engineer.

No man can draw precisely the line where the legitimate field of the carpenter, the road master, the contractor, or the manufacturer ends and the field of the architect or the engineer begins. A broad zone of uncertain classification lies between the legitimate fields of these non-professional workers and the field of professional men. Who will exactly define the limits? The courts of course. As a matter of the practical working of a law it is very clear that the courts will rule that structures of any kind that did not as a matter of practise require an architect or a professional engineer prior to the passage of the law, are not placed in the exclusive or monopolistic field of the architect or engineer by the law.

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While it might be financially advantageous to architects and engineers to establish a complete monopoly in the design and supervision of all structures, it would not be economically sound from the point of view of the public to require a professional fee of every man who wishes to build a warehouse, a cottage or a trestle. Nor would it be economically sound to require in the allied professions of medicine and law, a professional fee of every man who needed a dose of calomel or a bottle of liniment, or who should draw up a bill of sale, a warranty deed, or a lease. To hope to make of architecture and engineering permanently closed, monopolistic profession when neither medicine or law in the many decades of their licensing limitations have been able to accomplish this, is a dream which architects and engineers would better forget.

Perhaps the man who is to own the garage, the office building or the dam, is best qualified to decide whether he wishes a carpenter, an architect or an engineer to plan it and see to its building—or whether it is important enough to warrant the employment of "registered" men. It is quite certain that the good sense of the owner will secure to him,—with the aid of the discriminating registration law,—the services of competent men.

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We may feel sure that a registration law, which plainly separates the certified from the uncertified and prevents misrepresentation, will work to "promote the public welfare, by safeguarding life, health and property."

Very truly yours,
(signed) FRANCIS C. SHENEHON,
Chairman Joint Committee on Cooperation with Architects.

Copies of the recommended uniform law for registration of architects, engineers and land surveyors may be procured by addressing Alfred D. Flinn, Secretary of Engineerng Council, 29 West 39th Street, New York, N. Y.

CURRENT ENGINEERING TOPICS

PATENTS

The Nolan patent bill which passed both Houses of Congress during the last session following hearings at which Engineering Council's patent committee took a prominent part, will go before the Conference Committee immediately after the holiday recess. The Conference Committee which is headed by Senator Morris, who is also chairman of the Senate Patent Committee, will hold hearings to take further testimony in regard to the bill under its present status.

It is contemplated that the old Nolan patent bill with minor changes will become a law during the present session of Congress.

TARIFF HEARINGS

In contemplation of a special session of Congress after the present regular session the House, Ways and Means Committee has announced that it will hold hearings on the various tariff schedules between January 6th and February 16th.

These schedules contain many items affecting engineers' work. Schedule A covers chemicals, oils and paints and will be heard January 6-8. Schedule B covers earth, earthenware and glass and will be heard January 10-11. Schedule C covers metal and metal manufacturing and will be heard January 12-14. The free list will be taken up February 11-14.

FEDERAL POWER COMMISSION

Perhaps the most important item to engineers in the 1921 estimates was a relatively small item calling for a total appropriation of $482,065—the requirements of the Federal Power Commission for the fiscal year 1921. $100,000 it is estimated is required to reimburse executive departments for investigations requested by the Commission. General expense for authorized work of the Commission, exclusive of personnel, is estimated at $137,000 while salaries amount to $240,000. All of these estimates appear to be conservative, in fact, the lowest possible amounts that will permit of effective operation of the Commission under the requirements of the law.

Before these estimates can be acted on for appropriation by Congress under the law, it is necessary to so amend the existing power act as to permit the Commission to spend the money so appropriated. If the law is not amended giving the Commission its additional power, any appropriation bill carrying the items above referred to is subject to a point of order because regular appropriation bills cannot carry new legislation. It was evidently the intent of the original Federal power bill to give the Commission authority to hire and pay its personnel and to expend funds which were appropriated for it, but under a ruling of the controller of the Treasury these funds did not become available.

Engineers' attention is specially directed to the fact that the original bill provided a salary of $5000 for the executive secretary, which position is at present held by a prominent engineer who in private practise would normally be earning three or four times this amount. Some of his assistants are receiving as high as $7500 and a number of their assistants in turn are receiving more than the secretary's salary. This is a big job worthy of the best that the engineering profession can produce, but the salary has got to be corrected and corrected at once.

Since this whole appropriation and especially the question of the secretary's salary will affect practically every phase of the engineering field it is probable that engineers and engineering organizations as such should use their efforts to obtain, first, adequate legislation that will enable the Commission to properly expend this money and second, an appropriation that will permit of proper execution of the law. The need of this legislation and its proper administration is best shown by the fact that 115 applications for permits or licenses for power develop-

ment have been filed with the Commission in less than six months with an aggregate h. p. of over eight million.

It is a well-known fact that after every great war comes some correspondingly great development that offsets or at least tends to offset the losses and wastes of war, and it has been predicted that the water power development will fill that niche in the history that is now being written. The whole program in this country is in the hands of the Federal Power Commission. This is essentially an engineer's project because it affects ultimately practically every phase of engineering. Appropriate legislation will be introduced during the present session of Congress.

TECHNICAL WORK AT THE BUREAU OF STANDARDS

Recent bulletins issued by the Bureau of Standards cover the progress of experimental work that has been started there. The titles of those that are of special interest to engineers are itemized below:

1. Length measurements completed during the month.
2. Recent testing of the ice bar used in the standardization of tapes.
3. Recent weights and measures information.
4. Investigation of methods for measuring focal length of lenses.
5. Completion of a new laboratory telescope.
6. Recent chemical publication.
7. Report on hardeners for concrete floors.
8. Decarburization of steel by heating in vacuo.
9. The preparation of magnesia by a new method.
10. Recent metallurgical publications.
11. Electric resistance of the human body.
12. Airplane radio communication.

Because of the current nature of these investigations, the results are not generally printed, but complete data on all work to date are always obtainable.

THE 1921 ESTIMATES FOR THE BUREAU OF STANDARDS

The 1921 estimates cover the following amounts for work in which engineers are especially interested. The amounts asked this year as compared with the appropriation under which the Bureau is now working are indicated.

1. For apparatus, machinery, appliances, laboratory supplies, furniture for laboratories and cases for apparatus, \$90,000. This is an increase of \$15,000 over the current appropriation.

2. For metallurgical research, including alloy steels; properties of aluminum alloys; development of metal substitutes; investigation of new metallurgical processes, \$70,000. This is an increase of \$45,000 over the current appropriation.

3. For purchase, preparation and distribution of standard materials to be used in checking chemical analysis and in the testing of physical measuring apparatus, \$15,000. This is a new appropriation.

4. For the investigation of the problems involved in the electro-deposition of metals, \$15,000. This is a new appropriation.

5. For testing varnish materials, soap materials, inks, and chemicals \$50,000. This is an increase of \$20,000 over the current appropriation.

6. To develop color standards and methods of manufacture and of color measurement, with special reference to their industrial use in standardization and specification of colorants such as dye stuffs, inks, and pigments, \$12,000. This is an increase of \$2,000 over the current appropriation.

7. To study methods of measurement and technical processes used in the manufacture of pottery, tile and other clay products, \$25,000. This is an increase of \$10,000 over the current appropriation.

8. For the investigation of the problems involved in the production of optical glass, \$40,000. This is an increase of \$15,000 over the current appropriation.

9. To investigate textiles, paper leather and rubber in order to develop standards of quality and methods of measurement, \$40,000. This is an increase of \$25,000 over the current appropriation.

10. High-temperature measurement investigation, \$15,000. This is an increase of \$5,000 over the current appropriation.

11. To determine experimentally important physical contants of materials \$25,000. This is a new appropriation.

12. For the equipment, maintenance, and operation of a low-temperature laboratory and the production of liquefied gases, \$15,000. This is a new appropriation.

13. For an investigation of radio-active substances and the methods of their measurements and testing, \$15,000.

PERSONAL MENTION

W. G. STEARNS, for many years with the Standard Underground Cable Company, on the Pacific Coast, has been appointed Special Sales Agent.

R. L. JESSEE, of the M. B. Austin Company, Chicago, announces that the company has moved into its new building, located at 108-116 S. Desplaines Street, Chicago.

VINTON SMITH has been appointed Assistant Pacific Coast Manager of the Standard Underground Cable Company. He has been with the San Francisco office staff for several years,

W. G. SCHMAUDER has been appointed assistant general manager of the Texas Light & Power Company, Dallas, Texas. His duties will be of a general nature in looking after the various phases of the business.

GRENVILLE A. HARRIS has resigned his position as chief engineer of the American Steel Export Company, and has opened up an office of his own, Room 2914, Woolworth Building, New York, where he will operate as an export engineer, acting as consulting or advisory engineer on export to various manufacturers of this country.

E. J. WHITE and M. C. WRIGHT have severed their connections with the K. W. Electric Company, and have organized the Harris-Wright Company, Inc., to specialize on electric motor sales, repairs and maintenance and the engineering in connection with the application and installation of the above apparatus. The officers are located at 30-32 Liberty Street, Newark, N. J.

A. W. K. BILLINGS, of Barcelona, Spain, is in the States on a brief visit, his mail address being in care of the Engineers Club, New York City. Since 1912 he has been on the extensive hydroelectric and other work of the Ebro Company, filling the positions successively of manager of construction, managing director, vice president, and consulting engineer. During the war he was in charge of Naval Aviation construction in Europe, and was promoted to the rank of Commander and awarded the Legion of Honor and the Navy Cross for distinguished service in this work.

JAMES R. CRAVATH, owing to the ill health of one of his family, finds it advisable to move his residence to California, and therefore the firm of Fowle & Cravath has discontinued business. FRANK F. FOWLE announces that the new firm of Frank F. Fowle & Co. will continue the business at the same address, covering the field of electrical and mechanical engineering as heretofore. The advisory services of Mr. Cravath in

illuminating engineering matters will still be available, as he will retain a connection with the new firm for that purpose.

W. L. R. Emmet was awarded the Elliott Cresson Gold Medal by the Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts at its meeting November 17, 1920.

The wording of the award was as follows:

"After a careful consideration and study of Dr. Emmet's work relating to ship propulsion, the Institute is of the opinion that it deserves the highest award in its gift for the recognition of inventions of signal importance and awards to Dr. W. L. R. Emmet the Elliott Cresson Medal in recognition of his 'Notable Contributions to the Art of Ship Propulsion."

Richard G. Harris of the Standard Underground Cable Company succeeds as Pacific Coast Manager, Mr. John P. Bell, who will hereafter devote his time to the growing demands of his export and import business. Mr. Harris has been connected with the Standard organization since 1909 when he was a member of the staff of the general offices of the Company at Pittsburgh, and on special development matters at its Perth Amboy, New Jersey, factories, and later Sales Engineer with the New York office of the Company. For the past eight years he has been Manager of the Montreal office territory of the Standard Underground Cable Company of Canada, Ltd.

Ethan Viall, for ten years on the staff of the *American Machinist*, has resigned as editor-in-chief to become a member of the firm of T. W. Minton & Company, Barbourville, Ky., large producers of hickory dimension stock. Previous to joining the staff of the *American Machinist* Mr. Viall was for three years associate editor of *Machinery*, and before that he was for fourteen years foreman and superintendent in several of the largest specialty plants in the middle west. He is the author of "Electric Welding," "Gas Torch and Thermit Welding," "Broaches and Broaching," "United States Artillery Ammunition," "United States Rifle and Machine Guns," and "Manufacture of Artillery Ammunition." He is a Member of the Institute, of the American Society of Mechanical Engineers, and of the Society of Automotive Engineers.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK WANTED BY LIBRARY

The Engineering Societies Library desires to obtain one or two copies of the Manual du Repertoire Bibliographique Universal. Brussels: Institut International de Bibliographie. Any one having a copy for sale or knowing where one can be found, will please communicate with the Director of the Library, 29 West 39th St., New York.

BOOK NOTICES (FROM NOV. 1-30, 1920)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Applied Naval Architecture.

By W. J. Lovett. Lond. and N. Y., Longmans, Green & Co., 1920. 10 + 654 pp., charts, tables, diagrams, 9 x 6 in., cloth. $12.00.

Contents: Bilging—Board of Trade Requirements—Designing—Freeboard—Hydrostatic Curves and Captain's Information—Launching—Resistance and Horse Power—Rudders and Steering—Stability and Trim—Strength—Tonnage. Laws and Measurements—Weights, Stowages and Tables.

The present work is a specialized treatise on the design and construction of moderate-speed merchant vessels, 350 ft. and upwards in length. As naval architecture is not an exact science, absolutely accurate solutions are not necessary in many cases, and for these the author has given special attention to approximate methods, whereby results may be obtained rapidly.

A Builder of the New South; being the Story of the Life Work of Daniel Augustus Tompkins.

By George Taylor Winston. Garden City, N. Y., Doubleday, Page & Co., 1920. 8 + 403 pp., port., 8 x 6 in., cloth, $3.00.

The subject of this biography was born in South Carolina, in 1851. Educated at the University of South Carolina and Rensselaer Polytechnic Institute, he first became an assistant to Alexander L. Holley, and later an employee of the Bethlehem Iron Works, under John Fritz. In 1882, he established himself in Charlotte, N. C., and from that time, until his death in 1914, was active in the development of the industries of the South and the promotion of technical education. Because of his wide interests, the story of his life is, in no small measure, the story of the industrial reconstruction of the South.

Calcul des Organes des Machines.

By J. Boulvin. Paris, Gauthier-Villars et Cie, 1921. 9 + 515 pp., diagrams, charts, 10 x 7 in., paper.

The present work deals with the calculation of boilers, cylinders, pipe systems, rotating and reciprocating machinery, eccentrics, gearing and transmission systems. Throughout, it is concerned with the determination of their dimensions from the resistance of materials, so that the tension or deformation will not exceed the limits desired. Empirical formulas are avoided. Numerous difficult problems have been given special attention and are treated in a novel manner.

Chemical Reactions; Their Theory and Mechanism.

By K. George Falk. N. Y., D. Van Nostrand Company, 1920. 7 + 211 pp., 8 x 6 in., cloth, $2.50.

The central idea of this book is the development of a general theory of reactions which will include both inorganic and organic reactions. The theory set forth is based upon the "addition" theory that, when two or more substances react, a

primary addition is the first step. Although the addition theory has been used to explain isolated reactions, the author believes this to be the first attempt to apply it generally.

THE COLUMBIA BASIN IRRIGATION PROJECT, A REPORT OF COLUMBIA BASIN SURVEY COMMISSION.

Olympia, 1920. 185 pp., illus., maps, tables, diagrams, 9 + 6 in., cloth.

This report discusses the engineering, economic and financial aspects of a plan proposed for the irrigation of 1,753,000 acres of land in southeastern Washington, using water supplied by gravity.

THE CONSTRUCTION OF ROADS AND PAVEMENTS.

By T. R. Agg. Second edition, revised and enlarged. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 10 + 463 pp., illus., charts, diagrams, tables, 9 x 6 in., cloth, $4.00.

The present book was written to meet the need for a concise presentation of approved practise and of the principles involved. It is intended primarily for use as a textbook, but includes tables, typical designs and specifications valuable to highway engineers for reference use.

In this edition, the errors and omissions of the first have been corrected. New material has been added on assessments for pavements, on drainage, the control of erosion, maintenance, proportioning aggregates and on the testing of materials.

DICTIONARY OF EXPLOSIVES.

By Arthur Marshall. Phila., P. Blakiston's Son & Co., 1920. 14 + 159 pp., 9 x 6 in., cloth, $3.75.

It is a generation since a dictionary of explosives has been published, and in the meantime many new explosives have been introduced. It is therefore hoped that this small volume, giving concise information about them, may prove useful. The book is restricted to explosives with special or proprietary names, in order to keep it of moderate size. It gives brief data on the composition, use and source of the explosives mentioned.

ELECTRIC TRACTION AND TRANSMISSION ENGINEERING.

By Samuel Sheldon and Erich Hausmann. Second edition, revised. N. Y., D. Van Nostrand Co.; Lond., Crosby Lockwood & Son, 1920. 12 + 307 pp., illus., diagrams, charts, 8 x 5 in., cloth, $3.00.

This text-book attempts to present a prospective view of the design of a complete railway installation, from the cars to the power station, to indicate the nature and sequence of the various problems entailed, and to suggest or illustrate methods for their solution. It is intended to assist students and young engineers to discriminate as to the pertinency or necessity of specific details.

THE FIREMAN'S HANDBOOK AND GUIDE TO FUEL ECONOMY.

By Charles F. Wade. Lond. and N. Y., Longmans, Green & Co., 1920. 84 pp., diagrams, 7 x 5 in., boards. $1.00.

This little handbook explains clearly and concisely the correct way to fire and operate boiler and other furnace plants, and the reasons why the methods suggested are correct. The language is simple and can be understood by men with little ability to read.

HANDBOOK OF ENGINEERING MATHEMATICS.

By Walter E. Wynne and William Spraragen. Second edition, revised and enlarged. N. Y., D. Van Nostrand Co., 1920. 8 + 282 pp., diagrams, charts and tables, 7 x 4 in., cloth.

This is an endeavor to present in handy form and convenient pocket size, references to the theoretical and applied mathematics used in engineering. It contains the underlying engineering data and applications, as well as the mathematical formulas.

The present edition has been enlarged by additions to the mathematical sections and tables of functions, and the physical and chemical constants have been revised.

THE HANDBOOK OF INDUSTRIAL OIL ENGINEERING.

By John Rome Battle. Vol. 1. Lubrication and Industrial Oil Section. Phila. and Lond., J. B. Lippincott Co., cop. 1920. 8 + 1131 pp., illus., diagrams, tables, charts, 8 x 5 in., cloth. $10.00.

This handbook is intended to assist in the intelligent selection and use of lubricants for all purposes, and has been prepared for manufacturers, sellers and users of industrial oils. The range covered is a wide one and includes the use of oils in heat treating steel, in foundry practise, in soap making and as insecticides, as well as for lubrication. Specific information on the use of oils in the major industries is given. The book also has a section on marketing and a selection of mathematical and engineering data.

INDUSTRIAL STABILITY.

Edited by Carl Kelsey. (Vol. 90 of the Annals of the American Academy of Political and Social Science) Phila., 1920. 4 + 164 pp., 10 x 7 in., paper, $1.00

The thirty-four papers here brought together as contributions to current discussion of the general subject, present the views of business men, manufacturers, philosophers, social workers, attorneys and economists on one of the most pressing questions of the day. The major topics are the trend toward industrial democracy, labor representation in industrial management, collective bargaining, securing production, and industrial stability; and the individual papers are grouped accordingly.

LABORATORY MANUAL OF TESTING MATERIALS.

By William Kendrick Hatt and H. H. Scofield. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 10 + 178 pp., tables, chart and diagrams, 8 x 5 in., cloth, $1.25.

This concise manual of instructions for procedure in the usual physical tests of structural materials is the outcome of the operation of the Laboratory for Testing Materials of Purdue University. It is intended as a guide in class work and investigations and to explain the details of the methods.

The present edition has been thoroughly revised in accordance with current practise.

LESSONS IN MECHANICS.

By William S. Franklin and Barry MacNutt. Bethlehem, Pa., Franklin and Charles; Lond., Constable & Co., Ltd., 1919. 11 + 221 pp., diagrams, 9 x 6 in., cloth, $2.00.

LESSONS IN ELECTRICITY AND MAGNETISM.

By William S. Franklin and Barry MacNutt. Bethlehem, Pa., Franklin and Charles; Lond., Constable & Co., Ltd., 1919 (reprinted 1920). 16 + 254 pp., illus., diagrams, 9 x 6 in., cloth, $2.25.

LESSONS IN HEAT.

By William S. Franklin and Barry MacNutt. Bethlehem, Pa., Franklin and Charles; Lond., Constable and Co., Ltd., 1920. 11 + 147 pp., diagrams, charts, 9 x 6 in., cloth, $2.00.

These three volumes are intended to meet the needs of the two-year schedule in elementary physics which has recently been adopted in some technical schools, and in accordance with the opinion of the authors that most of the added emphasis involved in this schedule should be directed toward the mathematical basis of the subjects. The central idea of these texts is that mathematical training must be accomplished by the combined efforts of teachers of mathematics and teachers of physics, and the books are designed to help the latter to fulfill his proper function in this respect.

THE MANUFACTURE OF SUGAR FROM THE CANE AND FROM THE BEET.

By T. H. P. Heriot. Lond. and N. Y., Longmans, Green and Co., 1920. (Monographs on industrial chemistry). 10 + 426 pp., plates, diagrams, tables, 9 x 6 in., cloth, $8.50.

This is a systematic description of the manufacture of sugar, covering all the operations and elucidating the principles that underly them. Detailed descriptions of sugar machinery are omitted, as the book is intended to give a broad, but accurate view of the whole industry, rather than to cover the technical details of manufacture.

THE MINING CATALOG FOR THE YEAR 1920.

Compiled and Published Annually by the Keystone Consolidated Publishing Company, Pittsburgh. 1363 pp., illus., 12 x 9 in., cloth.

The editors of this volume have endeavored to produce a work of practical use to coal mine managers, purchasing agents and engineers. The book is divided into sections, each treating of a broad subject. Each division opens with a selection of technical information upon the subject, followed by descriptions of machinery used for the purpose, which have been prepared by the manufacturers and are condensed catalogs of their products. The volume is completed by good indexes of the firms and products represented.

MUNICIPAL LANDING FIELDS AND AIR PORTS.

Compiled and edited by George Seay Wheat. N. Y. and Lond., G. P. Putnam's Sons, 1920. 14 + 96 pp., map, plates, diagrams, 8 x 5 in., cloth.

The need for flying routes and landing fields is the most acute and immediate problem facing commercial aeronautics. Until these are provided, little progress toward the solution of other questions is possible. The present book is intended to present to the public the entire problem involved in creating and administering flying routes, landing fields and airports.

EIN NEUES PRINZIP FÜR DAMPF UND GASTURBINEN.

By Konrad Baetz. Leipzig, Otto Spamer, 1920. 80 pp., illus., diagrams, 10 x 6 in., paper.

The author states that the investigations described in this monograph have occupied his attention for twenty years, but that his inability to construct a model machine has caused him to publish his record of his work, in the hope that further investigations may be stimulated thereby.

The problem under consideration is that of combining, in a single machine, the modes of action of the reciprocating steam engine and the steam turbine. This the writer accomplishes by a "cellular" turbine, whose rotating member is composed of cells, in which the steam alternately is compressed and expanded. The book gives the theoretical calculations supporting the author's theory and the results obtained by experiment.

NOTES ON MAGNETISM.

By C. G. Lamb. Cambridge, The University Press, 1920. 8 + 94 pp., diagrams, 9 x 6 in., paper, $2.00.

These notes, drawn up for the use of students in the Engineering Laboratory, Cambridge University, contain an outline of such portions of magnetic theory as are required in order to read the ordinary technical textbooks with intelligence.

THE OIL SHALE INDUSTRY.

By Victor Clifton Alderson. N. Y., Frederick A. Stokes Co., 1920. 11 + 175 pp., illus., 9 x 6 in., cloth, $4.00.

CONTENTS: The Dawn of a New Industry—Nature, Origin and Distribution of Oil Shale—The History of Oil Shale—Mining Oil Shale—Retorting and Reduction—Experimental and Research Work—Economic Factors—Summary—Opinions—The Future—Bibliography.

Dr. Alderson's book is put forth as a general description of the industry, its history and its future, intended for the investor and business man, as well as for the engineer. As the industry is still in an experimental stage, he has not tried to describe any special processes in detail, but has confined himself to the discussion of the general scientific principles which must be followed, and to accounts of the experimental work now being done.

DIE PHYSIKALISCHEN UND CHEMISCHEN GRUNDLAGEN DES EISENHÜTTENWESENS.

By Walter Mathesius. Leipzig, O. Spamer, 1916. 16 + 439 pp., plate, tables, charts and diagrams, 10 x 7 in., cloth. (Purchase.)

In order that the reader's attention may be concentrated upon the physical and chemical principles involved in the metallurgy of iron, descriptions of the mechanical equipment and apparatus have been omitted, except when necessary to elucidate these principles. The book discusses in detail the physical and chemical laws and hypotheses, the fuels, the production of pig iron, wrought iron and steel, and the casting of iron and steel.

POWDERED COAL AS A FUEL.

By C. F. Herington. Second edition, revised and enlarged. N. Y., D. Van Nostrand Co., 1920. 12 + 338 pp., front., illus., diagrams, tables, 9 x 6 in., cloth, $4.50.

In the two years that have elapsed since the first appearance of this work, the use of powdered coal has been greatly extended, and the book is therefore reissued in order to present the economies that have been effected and the various uses to which powdered coal has been applied.

The processes for powdering coal, the suitable coals and the methods of using it are described in the introductory chapters. The remainder of the book gives the results obtained in various industries. A twenty page bibliography is included.

POWER WAGON REFERENCE BOOK, 1920.

Edited by Stanley L. Phillips. Chic., The Power Wagon Publishing Co., 880 pp., illus., tables, diagrams, 21 x 9 in., cloth.

This volume is a combination buyers' directory, encyclopedia and engineering handbook of motor trucks. The first section, on motor trucks, comprises lists of makers of trucks and truck parts, both gas and electric, tables of specifications, blueprints and articles on the use of trucks in various industries. Trailers, bodies and tractors are given similar treatment in succeeding sections, and these are followed by a collection of articles of a general nature. The book ends with a classified buyers' directory.

THE PRACTICAL DESIGN OF PLATE GIRDER BRIDGES.

By Harold Hughes Bird. Lond., Charles Giffin & Co., Ltd.; Phila., J. B. Lippincott Co., 1920. 8 + 180 pp., diagrams, 9 x 6 in., cloth.

This work, of English origin, has been written for young engineers and draftsmen engaged on the design of structural steelwork. It is particularly for those whose training has been more on the theoretical than the practical side and is intended to bridge the gulf between a knowledge of the principles of design and the actual application of that knowledge to the design of plate girder bridges and structural steelwork generally.

PRACTICAL RIVER AND CANAL ENGINEERING.

By R. C. Royal Minikin. Lond., Charles Griffin & Co., Ltd.; Phila., J. B. Lippincott Co., 1920. 7+123 pp., illus., diagrams, 9 x 6 in., cloth.

The author of this treatise is Chief Civil Engineer to the Brazilian Government Development Commission. His book is an endeavor to explain the principles underlying the successful treatment of inland waterways, and then to state concisely and clearly well-ascertained facts free from those data, such as dimensions and costs, that vary greatly with circumstances. The emphasis is therefore upon root principles rather than historic and economic details, and the author has drawn upon wide practical experience.

PROCEEDINGS, ANNUAL CONVENTION, INDUSTRIAL RELATIONS ASSOCIATION OF AMERICA, Chicago, 1920.

592 pp., 9 x 6 in., paper, $5.00.

The papers presented at this conference, held in May, 1920, are divided into two groups, one consisting of general problems, the other of those peculiar to specific industries. The collection covers a wide range of topics connected with the relations of workmen and employers.

PUMPING BY COMPRESSED AIR.

By Edmund M. Ivens. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1920. 6 + 266 pp., illus., tables, charts, diagrams, 9 x 6 in., cloth, $4.00.

The intent of the book is to provide the student with a comprehensive theoretical study of the subject and the operating engineer with information on the economic essentials of the actual installation. The present edition has been enlarged by thirty pages of reliable operative data.

RELATIVITY; THE SPECIAL AND THE GENERAL THEORY.

By Albert Einstein. Translated by R. W. Lawson. N. Y., Henry Holt & Co., 1920. 13 + 168 pp., port., 9 x 6 in., cloth, $3.00.

Dr. Einstein has attempted, as far as possible, to give an exact insight into the theory of relativity to those readers who are interested in it, from a general scientific and philosophical viewpoint, but who are not conversant with the mathematical apparatus of theoretical physics. The book assumes more than an elementary education and, despite the shortness of the book, a fair amount of patience and force of will, will be necessary to comprehend it. The author, however, has spared no pains in the endeavor to present the main ideas in the simplest and most intelligible form.

SPACE AND TIME IN CONTEMPORARY PHYSICS; AN INTRODUCTION TO THE THEORY OF RELATIVITY AND GRAVITATION.

By Moritz Schlick. Rendered into English by Henry L. Brose. N. Y., Oxford University Press, American Branch, 1920. 10 + 89 pp., 9 x 6 in., cloth, $2.50.

The theory of relativity consists of two parts, the old special theory, and the more recent general theory. This book is intended as an introduction to the whole set of ideas contained in this theory and should interest especially those who are concerned with the general conceptions rather than the details. Its essential purpose is to describe these physical doctrines with particular reference to their philosophic significance. The present edition varies from the previous one only in minor improvements.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Baltimore.—November 19, 1920, Johns Hopkins University. Subject: "The Transmission of Speech and Music Through the Mediums of the Piezo-Electric Effect in Crystals." Speaker: Alex. McF. Nicholson, Research Department, Western Electric Company. Attendance 155.

Boston.—November 30, 1920, Engineers Club. Paper: "Lightning Protection of Underground Systems." Speaker: Mr. D. W. Roper, Commonwealth Edison Co., Chicago, Ill. Attendance 125.

Cleveland.—November 16, 1920, Club Rooms of Cleveland Engg. Society. Paper: "Searchlight Development at the Lynn Laboratories of the G. E. Co." Speaker: Mr. C. A. B. Halvorson. Attendance 105.

Denver.—November 20, 1920, Metropole Hotel. Mr. H. F. Lunt, Commissioner of Mines for the State of Colorado, gave a very interesting and instructive address on "Electricity in Mining from a Standpoint of Safety." Mr. N. A. Carle also made some interesting remarks concerning the Central Station Operating Code which is in process of development under his supervision. Attendance 23.

Detroit-Ann Arbor.—November 12, 1920, Board of Commerce. Subject: "Characteristics and Applications of Transformers." The discussion was opened by Professor J. C. Parker, of the University of Michigan. A light lunch was served. Attendance 50.

December 3. 1920. Special meeting at the Michigan State Telephone Company; inspection trip through the main exchange dinner in the operators' dining room; talk by Mr. F. C. Kuhn, President of the Company. Attendance 130.

Erie.—November 9, 1920, Erie Public Library. The meeting was held in conjunction with the Engineers Society of Northwestern Pennsylvania. Paper: "Crystal Structure as Shown by X-Rays." Author: Dr. W. P. Davey, Research Laboratory, General Electric Company, Schenectady. Attendance 60.

Fort Wayne.—November 24, 1920, G. E. Co. Subject: "Farm Power and Light Plants." Speaker: Mr. O. E. Archibald, of the General Electric Company. Attendance 75.

Indianapolis-Lafayette.—November 4, 1920, University Club, Ind. Election of officers as follows: Chairman, J. Lloyd Wayne; Secretary, D. C. Pyke. Attendance 33.

Los Angeles.—November 23, 1920, Edison Hall. Subjects: "The Edison Plan, An Adventure in Democracy" by Mr. H. A. Barre; "The Kerckhoff Power Development," by Mr. R. C. Starr. Attendance 102.

Lynn.—November 17, 1920, G. E. Hall. Subject: "Submarine Detection and Acoustical Aids to Navigation." Speaker: Professor G. W. Pierce, of Harvard University. The talk was illustrated by lantern slides which showed the apparatus and illustrated the methods used in sound detection and location. Attendance 250.

Madison.—November 3, 1920, Engg. Bldg., University of Wisconsin. Subject: "Accident Prevention." Speaker: Mr Charles B. Scott, Bureau of Safety, Chicago. Attendance 70.

Milwaukee.—November 24, 1920, City Club. Subject: "The Twentieth Century's Contribution to Our Knowledge of the Atom." Speaker: Dr. R. A. Millikan, Chicago University. Attendance 370.

Pittsburgh.—November 9, 1920, Chamber of Commerce. Subject: "Transmission Lines." Speaker: Mr. M. E. Noyes. Aluminum Company of America. The discussion which followed was very full, the following contributing: Messrs. J. S. Martin, W. Partridge, H. N. Mueller, F. Howard, N. J. Wahberg, H. L. Christie, R. H. Marvin, Sindeband and Jorstad. Attendance 150.

Portland.—November 23, 1920, University Club. Joint meeting of Portland Sections of A. I. E. E. and N. E. L. A., and Oregon Association of Electrical Contractors and Dealers. Mr. G. E. Armstrong, Pacific Coast Editor of the *Electrical World*, gave a most interesting talk on "Northwest Development." A moving picture entitled "The Conquest of the Forest," dealing with electricity in the lumber industry, taking the tree from the time it is felled through the sawmill to the completed house, was shown. Attendance 75.

Providence.—December 3, 1920, Providence Engg. Society Rooms. Subject: "The Manufacture and Application of the Electric Incandescent Lamp." Speaker: Mr. W. E. Smith, of the Bryan-Marsh Division of the National Lamp Works. Attendance 17.

Rochester.—November 26, 1920, Subject: "Valuation of Public Utilities." Speaker: Mr. L. R. Brown, of the New York State Railways. Attendance 24.

St. Louis.—November 17, 1920, Union Electric Hall. Subject: "Illumination." Speaker: Mr. Stickney, of the Edison Lamp Works of General Electric Company, Harrison, N. J. Attendance 80.

San Francisco.—October 29, 1920, Engineers Club. Papers: "Construction of the Kerckoff Power Project of the San Joaquin Light & Power Corporation," by Mr. R. C. Starr: and "Description of a 100,000-Volt Wood Pole Transmission Line and the Economic Questions Governing the Choice of this Type of Construction," by Mr. L. J. Marre. Attendance 115.

Schenectady.—November 19, 1920, Edison Club Hall. Subject: "The Twentieth Century's Contribution to Our Knowledge of the Atom." Speaker: Dr. R. A. Millikan, Professor of Physics of the University of Chicago. Attendance 300.

December 3, 1920, Edison Club Hall. Subject: Modern Photography." Speaker: Mr. Arthur Palme, of the Transformer Engineering Department of the General Electric Company, Pittsfield, Mass. Attendance 275.

Seattle.—November 16, 1920, Bagley Hall, Univ. of Washington. Paper: "Radiant Energy and Its Relation to Matter, Space and Time." Speaker: Mr. J. D. Ross. The paper was illustrated with numerous original lantern slides and experiments with special apparatus to demonstrate several new and startling theories which Mr. Ross advanced. Attendance 500.

Syracuse.—November 17, 1920, Assembly Hall. Subject: "The Engineer and Industry." Speaker: Mr. D. B. Rushmore, of the General Electric Company, Schenectady, N. Y. An informal talk was given by Mr. E. W. Pragst, of the General Electric Company, on "Power Stations." Attendance 152.

Toronto.—November 26, 1920, Toronto University. Paper: "Steam vs. Electrical Drive as Applied to the Steel Industry." Speaker: Mr. E. S. Jefferies. Chief Electrical Engineer of the Steel Company of Canada. Attendance 107.

Utah.—November 16, 1920, Commercial Club. Papers: "Early Electrical Experiences in Utah," by Mr. E. G. Holding; and "Inductive Interference Problems," by Mr. P. A. Jeanne. Attendance 61.

Vancouver.—November 5, 1920. Subject: "Some Features of Electrical Precipitation." Speaker: Dr. J. G. Davidson of the University of British Columbia. Attendance 12.

December 3, 1920. Subject: "Automatic Telephones." Speaker: Mr. E. P. LaBelle, Superintendent of the British Columbia Telephone Company. Attendance 31.

Washington.—November 18, 1920, McKinley Manual Training School. Subject: "The Construction of Controllers for Electric Motors." Speaker: Mr. H. D. James, of the Westinghouse Elec. & Mfg. Co. Attendance 125.

Worcester.—November 30, 1920, Worcester Polytechnic Institute. Subject: "Niagara Power Development." Speaker Mr. J. Allen Johnson, Niagara Falls Power Company. The address was illustrated with motion pictures and stereopticon views. Attendance 105.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—November 4, 1920. Professor W. W. Hill made a short but interesting talk on the advantages to be derived by the student in belonging to the Institute. Mr. F. E. Bell also spoke on "The Attitude of Older Engineers towards Students." Attendance 27.

November 18, 1920. Short talks were given by Messrs. J. W. Shealey and H. L. Biggin on "The General Electric Company's Student Course." Attendance 14.

December 2, 1920. Short talks were given on the "Westinghouse Students' Course," by Mr. J. H. Lasseter and Professor W. W. Hill. Professor Hill also gave a short talk on the "Doherty System of Training Graduates." Attendance 26.

University of Arkansas.—November 16, 1920, Engineering Hall. Subjects: "Motor Vehicle—Competer or Ally," by Mr. Shem Hollabough; "600,000-h. p. Line Delivers Niagara Power," by Mr. Jack Thompson; "Ultimate Boiler Capacity Limited by Design and Operation," by Mr. R. Jacobs. Attendance 16.

Armour Institute of Technology.—November 5, 1920. Subjects: "Uses of the Electric Furnace," by Mr. R. J. Grant; "Some Applications of Vacuum Tubes." by Mr. W. W. Pearce; "Electrically Driven Unloading Systems on Lake Vessels," by Mr. M. R. Mehrhof. Attendance 57.

November 19, 1920. Subject: "Burning up a 750-Volt Turbo Alternator." Speaker: Mr. T. E. Grube. Attendance 27.

Brooklyn Polytechnic Institute.—November 12, 1920, Institute Chapel. Joint meeting of Branches of A. I. E. E. and A. S. M. E. The program included introductory talks by the Chairmen of both Branches, motion pictures, and a lecture on "The Engineer's Liability to Failure," by Mr. Herbert A. Wilkinson. Attendance 190.

Bucknell University.—November 22, 1920. Illustrated lecture by Prof. V. B. Hall on "Porcelain Insulators from the Clay Bank to the Cross Arm." Attendance 17.

December 9, 1920. Election of officers as follows: Chairman, L. F. Worthington; Secretary, E. LaRue Worthington. Attendance 8.

California Institute of Technology.—November 19, 1920, Gnome Club House. Talks were given by Professor R. W. Sorensen on "The Present and Past of A. I. E. E."; Professor Franklin Thomas on holding joint meetings of the different engineering societies; and suggestions by Professor George Foster. Refreshments were served. Attendance 27.

University of California.—November 17, 1920. Illustrated talk by Mr. Anderson, Chief Engineer of the Stone & Webster Company, on "The Caribou Plant Development." Attendance 43.

December 1, 1920. Election of officers as follows: Chairman, N. C. Youngstrom; Vice-Chairman, J. N. Kieth; Secretary, P. L. Wyche; Treasurer, F. C. Krasny. Attendance 20.

University of Cincinnati.—November 2, 1920. Subject: "Some Lost Opportunities in Electrical Work." Speaker: Mr. L. T. Milner, President of the Milner Electric Company. Attendance 70.

November 9, 1920. Subject: "Some Mile-Stones in Electrical Work." Speaker: Prof. C. B. Hoffman. Attendance 91.

November 16, 1920. Subject: "The New West End Station of the Union Gas & Electric Company." Speaker: Mr. F. D. Wyatt, of the Union Gas & Electric Company. Attendance 86.

Clemson College.—November 19, 1920. Subjects: "Automobile Ignition," by Mr. W. D. Banks; "Starting and Lighting Systems," by Mr. C. G. Haas; "Current Events," by Mr. C. O. DuRant. Attendance 27.

Drexel Institute.—November 19, 1920. Subject: "Electrical Layout of Large Generating Stations" (with lantern slides). Speaker: Mr. Robert Hentz. Attendance 34.

Georgia School of Technology.—November 18, 1920. Subject: "Long Distance Telephonic Transmission." Speaker: Mr. L. S. Crosby, A. T. & T. Co. Attendance 29.

University of Kansas.—November 20, 1920. Subjects: "Rate Making for Telephone Service," by W. H. Beltz: "Telephone Circuits and Troubles," by H. Havenhill. Attendance 44.

December 1, 1920. Subject: "Telephone Repeaters." Speaker: Seymore Cronk. Attendance 22.

University of Kentucky.—November 15, 1920. Subject: "Development of the Audion Bulb," by E. L. Balch. Paper read from September issue of JOURNAL, "Features of the Substation at the Hog Island Shipyard." Attendance 22.

Lehigh University.—December 10, 1920. Subject: "Outdoor Substations and Switching Equipment" (illustrated). Speaker: Mr. S. Q. Hayes, Westinghouse Company. Attendance 78.

Massachusetts Institute of Technology.—December 9, 1920. Subject: "Homopolar Generator." Speaker: Mr. F. B. Philbrick, Gamewell Fire Alarm Co. Attendance 60.

School of Engineering of Milwaukee.—November 19, 1920. Subject: "Development of Electric Power from Niagara Falls." Speaker: Mr. Joseph Pheiffer, of the American Appraisal Company. Attendance 78.

University of Minnesota.—November 12, 1920. Subjects: "Human Electrons," by Samuel A. Berg; "Summer Experiences in a Small Central Station," by Ralph W. Liddle; "How to Become an Electrical Engineer," by Boyd Phelps. Motion Pictures: "Keokuk Dam," and "Itasca State Park." Refreshments were served. Attendance 50.

University of Missouri.—November 2, 1920. Subject: "Industrial and Commercial Power Rates." Speaker: Mr. Delmar Hasenritter. Attendance 40.

November 15, 1920. Paper on "Cooperation between Engineering Schools and Utilities" (originally prepared by Dean H. B. Shaw) read by Mr. W. C. Wheeler. Attendance 60.

November 22, 1920. Subject: "The Control for Industrial Motors in Industrial Service." Speaker: Mr. R. S. Coulter. Attendance 55.

North Carolina State College.—November 16, 1920. Business meeting. Attendance 33.

November 23, 1920. Captain Cox gave a lecture on "Radio" and accompanied this by a demonstration of apparatus. Attendance 38.

November 30, 1920. Mr. Couch, of the Comberland Railway & Power Company, told of some of his experiences at college and since his graduation. Attendance 35.

University of North Carolina.—November 5, 1920. Subjects: "Before Graduation, What;" by Professor P. H. Daggett; "After Graduation, What?" by Professor J. H. Mustard; "Summer Work, Its Attractions and Advantages," by Mr. Wright; "Enthusiasm, How Obtainable in the Society," by Mr. Wells.

November 19, 1920. Subjects: "Manufacture of Steel Rails," by R. M. Casper; "National Tube Works," by P. C. Smith; "Electrical Factory Work," by M. E. Lake; "Operation of Electrical Machinery," by J. W. Taylor. Attendance 45.

December 3, 1920. Subject: "A modern Telephone Exchange." Speaker: Professor J. E. Lear. Attendance 40.

Ohio Northern University.—December 8, 1920. Subjects: "Metric System," by E. A. Erdman; "Electric Heating," by Everett L. Bird. Attendance 21.

Ohio State University.—November 18, 1920. Talks by students on Summer experiences. Refreshments were served. Attendance 83.

Oklahoma Agricultural and Mechanical College.—December 7, 1920. Subjects: "Cost of Interruptions of Power to Steel Mills," by M. C. Courtney; "Power Development in the Southern States," by Carl Soerner; "Storage of Coal for Central Stations," by C. E. Taylor. Attendance 17.

Oregon State Agricultural College.—November 17, 1920. Subject: "Development of High-Voltage Direct-Current Railways." Speaker: Professor F. O. McMillan. Attendance 63.

University of Pennsylvania.—November 2, 1920. Subject: "Student Course at Westinghouse Elec. & Mfg. Co." Speaker: Mr. G. G. Herrick. Attendance 22.

November 9, 1920. Subject: "Student Course at General Electric Co." Speaker: Mr. R. W. Perkinpine. Attendance 22.

November 16, 1920. Subject: "Power Plants at Niagara Falls." Speaker: Mr. E. C. Muller. Attendance 22.

November 23, 1920. Subject: "Manufacture of Storage Batteries." Speaker: Mr. N. R. Guilbert. Attendance 22.

November 30, 1920. Subject: "Applications of Storage Batteries." Speaker: Mr. J. Austin. Attendance 22.

Purdue University.—November 9, 1920. Subject: "Transformers." Speaker: Mr. E. A. Wagner, of the General Electric Co., Fort Wayne, Ind. Attendance 145.

November 23, 1920. Subject: "Methods of Determining Transformer Costs." Speaker: Mr. J. G. Bailey. Attendance 66.

Rensselaer Polytechnic Institute.—November 9. 1920. Subject: "Electric Propulsion of Ships." Speaker: Mr. Eskel Berg, of the General Electric Company. Attendance 234.

Syracuse University.—November 9, 1920. A short talk on "Radio Telegraphy" was given by Mr. Hines. Attendance 13.

November 16, 1920. Subject: "Vacuum Tubes." Speaker: Mr. Fauss. Attendance 13.

November 30, 1920. Subject: "Electric Furnaces." Speaker: Mr. Chapman. Attendance 13.

Texas Agricultural & Mechanical College.—November 23, 1920. Subjects: "Electrification of Railways—General Views," by Mr. F. E. Woods; "Financing Central Power Stations," by Mr. D. D. Murphree; "The Inspection Trip of the E. E. Juniors of Texas A. & M. College of June 1920," by Mr. A. S. Legg. Attendance 44.

University of Texas.—November 15, 1920. Election of officers as follows: Chairman, C. H. Marshall; Secretary, Treasurer, F. J. Domingues. Attendance 30.

December 6, 1920. Papers: "D-C. Transmission Lines," by O. L. Bryan; "A-C. Transmission Lines" (describing special features of long large capacity lines) by R. S. Munger; "A-C. Transmission Lines" (construction of lines from economic side) by Edward Price; "A-C. Transmission Lines" (featuring maintenance and insulation) by E. W. Franke. Attendance 18.

Virginia Military Institute.—December 3, 1920. Paper read by Mr. Lockey on "Transmission Lines." Illustrated talk by Mr. Bellheimer on the Delco farm lighting plant. Attendance 49.

University of Virginia.—November 11, 1920. Subject: "Inspection Tour of the General Electric Lamp Works, made as Part of Summer School Course of Lehigh University." Speaker: Mr. Gildersleeve. Attendance 14.

University of Washington.—November 9, 1920. Subject: "The Engineer." Speaker: Professor Loew. Attendance 49.

West Virginia University.—November 15, 1920. Subjects: "Object and Work of the American Institute of Electrical Engineers," by Max Wilcoxen; "Gaseous Conductor Light," by J. M. Frum; "Electric Furnaces," by A. C. Price; "Interpoles on Motors," by A. E. LaPoe; "High-Frequency Iron Losses," by R. L. Sheffer; Informal talk by Professor A. H. Forman. Attendance 13.

University of Wisconsin.—December 2, 1920. Subject: "Automatic Telephony and Automatic Telephone Apparatus." Speaker: Mr. R. E. Hantzsch. Attendance 30.

ENGINEERING SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

SERVICES AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after an interval of three months, during this period names and records will remain in the active files.

NOTE.—All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to the ENGINEERING SOCIETIES EMPLOYMENT BUREAU, 33 West 39th Street, New York City, the employment clearing house of the National Societies of Civil, Mining, Mechanical and Electrical Engineers.

OPPORTUNITIES

INSTRUCTORS: All engineers willing to consider teaching positions are invited to register with Engineering Societies Employment Bureau. The Bureau has been called upon to fill more positions, varying in grade from laboratory assistant to heads of departments in various engineering and technical schools of this country, than it has been able to do from among the men now registered. Blanks for purpose of registration and information regarding the Bureau may be had by addressing W. V. Brown, Manager, 29 West 39th Street.

YOUNG MAN with technical training to assist in installation and repairing tower and electric clocks. Experience unnecessary. State age, mechanical and electrical training and salary expected. Location New York City. Z-2609.

MANAGING EDITOR for drug trade Journal. Graduate engineer. Must have managing editorial experience. Location New York City. Z-2592.

INSTRUCTOR IN ELECTRICAL ENGINEERING. Duties beginning in January, 1921, in Technical School, Western Pennsylvania, mainly instructor in Electrical Engineering Laboratory. Graduate of one or two years' experience desired. Z-2595.

CABLE ENGINEER, must be able to write specification, design and give approximate valuation. Application by letter. Only engineer with cable experience will be considered. Permanent position. Location New York City. Z-2569.

SYSTEM OPERATORS. Position similar to that of Load Dispatcher. Men control completely the operation of a 90,000-k. w. system, approximately two hundred miles long in each direction, and including three 30,000-kilowatt plants with many smaller ones, and completely linked together with 66,000 and 110,000-volt transmission system. Should have had enough power house experience to be thoroughly acquainted with operation of large central station and enough electrical experience to enable them to handle the switching, testing, grounding of lines and such similar operation as would arise in handling of such a large transmission system. Prefer technical men, who are able to carry weight with men in charge of large central stations, so that they can give such men instructions in

cases of trouble and command their respect. Position will pay enough to interest men of this calibre and is a splendid opportunity for any one interested in public ulitity work of this nature. Gives opportunity to thoroughly study and handle all of points arising in the operation from the coal pile to the customer. Location Penna. Z-2545.

ELECTRICAL OR MECHANICAL UNIVERSITY GRADUATES wanted for sales work with a well established Electrical manufacturer in the middle west. Correspondence confidential. Give all particulars. Location Mo. Z-2456.

ELECTRICAL ENGINEER with from 4 to 7 years experience in design of direct-current motors and generators of sizes below 5 h. p. State age, education, experience, married or single, and salary expected. Excellent opportunity for man with proper characteristics. Location Penna. Z-2537.

ELECTRICAL ENGINEER. Desirable position open for young engineer on design and application of direct-current and commutating machines below 3 h. p. Should have from 2 to 4 years experience. Specify salary expected, experience, married or not, and education. Location Penna. Z-2538.

INSTRUCTOR in Electrical Engineering. Candidates should be graduates in electrical or mechanical engineering from technical institution of recognized standing. Duties will comprise supervising laboratory experiments, lecturing and holding recitations on laboratory work, and correcting laboratory reports. Work covers ordinary branches of electrical engineering; and it is our custom to change the specific work of each instructor from year to year, so that he will become familiar with all parts. Location New Jersey. Z-2541.

DESIGNING ENGINEERS experienced in electric and mechanical engineering apparatus. Location New York State. Z-2526.

ENGINEERS. A few men with technical training and electrical laboratory experience. The applicant should be familiar with laboratory instruments and possess some ability to engage in development and research work. Location Penna. Z-2531.

SWITCHBOARD ENGINEER OR POWER HOUSE OPERATOR. Wanted, young technically trained engineer with experience as switchboard designer or as power house and substation operator. In reply give experience and age. Location Penna. Z-2532.

ELECTRIC DISTRIBUTION ENGINEER; give salary desired as well as detail information as to training and experience. One to two years experience in either general electric or Westinghouse test department preferred. Graduate electrical engineers of a public utility, also experience in steam work will be an advantage. Location South Carolina. Z-2533.

TECHNICALLY EDUCATED MAN, must have editorial experience, initiative and judgment, for position of responsibility. Replies should embody the essential facts. Z-2497.

INSTRUCTOR of Electrical subjects. Good engineering training and experience. Location Kansas. Z-2507.

INSTRUCTOR in Mining Engineering. Should have a reasonable amount of experience. Location China. Z-2491.

PHYSICIST, who has had doctor degree from two to five years. Experienced in general and electron physics. High grade man wanted. Location New Jersey. Z-2167.

RADIO AND ELECTRIFIERS TUBE ENGINEERS. Should be physicist in Electrical Engineering. Two men needed. One for radio tubes and one for rectifiers. Location New Jersey. Z-2169.

ENGINEER with knowledge of outside wiring to design and develop a line of electric pole line devices for large manufacturing company in central west. Give full details of experience and salary in first letter. Location Pa. Z-2144.

SALES ENGINEER; to sell power house equipment in Detroit. Attractive proposition to experienced man. Give full history and earning capacity in reply. Location Michigan. Z-1931.

ELECTRICAL ENGINEER, must be a college graduate with technical training and must know something about telegraph engineering, preferably having had some practical experience in that line. No one over 35 years of age will be considered. Application by letter only. Location New York City. Z-1936.

YOUNG MAN, about 25 years of age, with an appreciation for and not intolerant to engineering problems. Should know something about magnetic apparatus and be particularly strong on the subject of humidity, how to measure and control it. Location New York City. Z-1672.

INDUSTRIAL PHYSICIST or Engineer interested in research or electrical control problems. Location Middle West. Salary according to training and experience. Location Wisconsin. Z-1525.

DESIGNER, thoroughly familiar with the full line of sockets, receptacles, etc., and with a workable knowledge of the necessary tools and dies. Location New York. Z-2610.

DRAFTSMAN—A large power company in the south has openings for a few graduate engineers and draftsmen with experience in the design of hydroelectric power plants. Give full information in the first letter. Location Ala. Z-2625.

COMMERCIAL RAILWAY ENGINEER—Technical graduate who is interested in railway electrification. Experience along this line is not necessary, but may be an advantage. A man capable of growing into a high class railway salesman and application engineer is desirable. Location Penna. Z-2626.

SUPERINTENDENT for company manufacturing storage batteries. Must have had battery experience. Application by letter giving details. Location New York City. Z-2339.

ELECTRICAL ENGINEER for research work in electrical laboratory. Location Wisconsin. Z-1676.

YOUNG MAN with technical training to assist in installation and repairing tower and electric clocks. Experience unnecessary. State age, mechanical and electrical training and salary expected. Location New York City. Z-2609.

MEN AVAILABLE

YOUNG TECHNICAL GRADUATE, Age 25, single. One year shop experience and six months commercial experience with large electrical manufacturer. Desires position with consulting engineering firm, construction company or industrial plant. E-2443.

ELECTRICAL AND MECHANICAL ENGINEER. Age 32, college education. Twelve years engineering experience, manufacturing, steel plant, R. R., Several years inspector charge of tests and construction. Designer and chief draftsman. Good worker. Desire location as chief draftsman, designer, assistant manager or similar. E-2444.

TECHNICAL GRADUATE, age 25 married. Protestant. Five years experience, draughting, marine work, wiring, electric meters, machine shop, electrical testing. Assoc. A. I. E. E. Desire position with chance for advancement. Available immediately. E-2445.

ELECTRICAL AND MECHANICAL ENGINEER. Ten years practical experience, maintenance street and electric railway rolling stock. Six years practical experience, operation of hydroelectric power plants and substations. Desires responsible position in either of above branches. Good references. Age 30. Now in charge of hydroelectric power plant. Location anywhere. E-2446.

ELECTRICAL ENGINEER AND DRAFTSMAN. Technical graduate. Wide experience in illumination and power design. At present chargeman on electrical design with one of leading shipbuilding concerns. Can produce results. Particularly well adapted for electrical part in connection with merchant shipbuilding. Desires position in or near Philadelphia. E-2447.

ELECTRO-MECHANICAL ENGINEER. Cornell. Age 25. Four years broad experience including two years General Electric Company test. Must locate in immediate vicinity of New York City. Desires position requiring good engineering sense and business ability combined, with good opportunity for advancement. Small growing concern preferred. E-2448.

*ELECTRICAL ENGINEER, technical graduate, with four years experience in details and general problems of telephone and central office engineering. Desires position offering broader opportunity for advancement. Reliable, willing and hard worker. Capable of supervising. Present salary $2700. Available on 30 days notice after latter part of January. E-2449.

SUPERINTENDENT OR ASSISTANT SUPERINTENDENT of medium size or small central station property. Hydroelectric preferred, but not essential. Experience in practically all departments. Age 30, single. Hard worker, technical education. Now assistant superintendent of 1200 kw. system. Can give satisfactory references. Available upon short notice. E-2450.

ELECTRICAL ENGINEER. Seven years experience. Two years station operation, balance station and industrial power design and installation. At present in charge of design and installation of electrical apparatus, power station and plant which it serves. Desires change. Age 29, married. Technical education. Available in two weeks. E-2451.

GRADUATE ELECTRICAL ENGINEER wishes business or engineering position with growing concern near Boston. Six years office and field experience in power plant and distribution design including some mechanical and civil engineering experience. B. S. Tufts College. Familiar with contract work, estimating and power equipment. E-2452.

MECHANICAL ELECTRICAL ENGINEER, technical graduate (1908). Experience covers design, construction, purchasing and operation of mechanical, electrical, hydraulic and refrigerating plants and equipment, also heating and ventilating, and building construction, fire protection, appraisal of engineering properties, investigations and reports. Desire position with consulting engineer or large concern where broad experience is essential. E-2453.

MANAGER, SUPERINTENDENT, or Executive electrical engineer. Technical graduate. Twenty-two years experience in steam and hydroelectric power plants, electric railways systems, high-tension transmission, low-tension distributing system and industrial layouts. Broad experience with public utility. Lately manager and engineer at hydroelectric power plant. Salary commensurate with position. Available immediately. E-2454.

GRADUATE ELECTRICAL ENGINEER with three and one half years' public utility experience in construction and maintenance of street railway and light companies properties. Desires change offering broader opportunities. Salary $200 or thereabout. Experience includes thorough central station and substation work under the Supt. of Line distribution, drafting, accounting and appraisal engineering. E-2455.

ELECTRICAL ENGINEER, age 40. Broad supervisory experience in central station, substation, transmission and industrial constructive, maintenance and operative. Training secured with large public utilities and contracting engineers. Salary $4000. E-2456.

SALES MANAGER or sales engineer, age 36, married. Thoroughly familiar with generally used electrical and mechanical apparatus and many specialties. Understand thoroughly design, manufacturing, installation and operating. E-2457.

TECHNICAL GRADUATE, age 25. B. S. degree in electrical engineering. Would like to locate with concern affording opportunities for the future. Wisconsin or vicinity preferred. Would like to build up in power plant work, but will consider any other good offer. Services available in January. E-2458.

MECHANICAL ELECTRICAL ENGINEER. Twenty years experience in design, development and manufacturing of motors, generators, fractional horse power motors, instruments, wireless apparatus and mechanical and electrical apparatus, and devices of every description. E-2459.

YOUNG ELECTRICAL ENGINEER, 1918. At present employed as purchasing inspector by large interests and desires to stop continuous traveling. Broad practical experience. Familiar with shop production of large power equipment. Wishes position as purchasing engineer or equipment engineer. New York City or vicinity. Present salary equivalent $200 per month. E-2460.

ELECTRICAL SUPERINTENDENT OR MANAGER. Age 36, married. Good personality. Twelve years foreman and superintendent in all classes insulation, construction and maintenance electrical and mechanical. Qualified to oversee large amount of work, both field and office with high efficiency. Exceptional ability for handling men. Now employed. Available on short notice. E-2461.

INDUSTRIAL RESEARCH ENGINEER with associated chemist, desires connection with group of manufacturers for the development and design of special processes and machinery. Cornell graduate 1904. Extensive experience in mechanical and electrical engineering. Preferred location, Central New York. E-2462.

EXECUTIVE POSITION WANTED. Age 33, experienced in steam and hydraulic generation, high-tension transmission and street railway operation. Formerly apprentice with Westinghouse Electric & Mfg. Company. Absolute loyalty to organization. Open for engagement on two weeks notice. At present assistant general superintendent in large power company. E-2463.

ELECTRO-MECHANICAL ENGINEER. Married, age 26. Technical graduate. Designed and built electrical installation at large oil refinery. At present in charge electrical and mechanical work at refinery. Central station experience, boiler operation, stores and accounting supervision, pyrometry expert. Desires executive position in Texas. Minimum salary $3000. E-2464.

ELECTRICAL ENGINEER, age 35. Technical graduate of highest standing. Ten years experience in design of electrical machinery, contributor to technical literature. Desires position in research and development work. E-2465.

ELECTRICAL ENGINEER, graduate 1915. Married, age 31. Seven years experience in construction, operation and maintenance of high and low-tension equipment in large hydroelectric concern. At present in charge of operation and maintenance of hydroelectric station, substations, and large motors in industrial plant. Available 30 days. Salary to be equivalent to $3500. E-2466.

ELECTRICAL ENGINEER. Cornell graduate. 1914 M. E. degree. Three years power plant and three and one-half years in charge operation, maintenance, sales, all electrical equipment, also correspondence and purchasing machinery and supplies. Best references. E-2467.

GRADUATE MECHANICAL AND ELECTRICAL ENGINEER. Age 27. B. Sc. London University. Speaks fluently French and Russian with 2½ years testing experience with leading British firm. Desires progressive post with important American or Canadian firm. E-2468.

ELECTRICAL ENGINEER graduate desires position as assistant in engineering department of some manufacturer of electrical apparatus, or position with public utility. Would also consider position where opportunity is given to develop as sales engineer. Have had varied experience in testing and maintaining electrical apparatus. Age 27. Willing to start at a moderate salary. E-2469.

INSTRUCTOR ELECTRICAL ENGINEER, age 27. Technical graduate, degree B. S. 1917. Desires teaching position in technical school or college in electrical engineering, mathematics or physics. Location in or near New York. E-2470.

ELECTRICAL ENGINEER (general). Technical graduate. Wide practical experience of fifteen years in design, construction, testing and operating of electrical equipment for power stations, substations, factories, private and public plants and railway electrification. Will accept position regardless of locality. New York preferred. E-2471.

MECHANICAL-ELECTRICAL ENGINEER. Services of experienced engineer available for part time to supervise power plant operation and to assist on engineering problems. At present engaged on similar work in industrial plants located in New Jersey and New England, and can furnish credentials from present employers. E-2472.

TECHNICAL GRADUATE (B. S. in Electrical Engineering). Age 31. Desires connections with medium sized or large operating company in capacity of electrical engineer or assistant electrical engineer. Has had general experience in central station distribution and transmission construction, maintenace and operation in all grades from electrician's helper to assistant chief engineer on property of 35,000 kv-a. capacity. Three years as chief engineer for holding company operating in three states. Will consider any location. Available January 15th. E-2473.

ELECTRICAL ENGINEER, with twelve years experience in manufacture, construction, testing, design, etc., of electrical machinery and devices. Eight years teaching experience. At present electrical engineer and works manager with company manufacturing electrical and mechanical devices. Broad experience on efficiency, production and management Desires to connect with progressive company. Open for engagement on four weeks notice. Member A. I. E. E. E-2474.

ENGINEER. Age 32, married. E. E. degree. Desires position with public utility or manufacturer. Trained and equipped for executive, sales, organization and administrative positions. Ten years experience in machine shop, drafting, and seven years business manager of hydroelectric plant serving 40,000 consumers. In charge of new business, contract, accounting, statistical, billing and appliance departments of 125 employees, and one and a half years similar experience with manufacturing company. E-2475.

ELECTRICAL ENGINEER, foreign graduate, age 31, single. Broad engineering experience. At present on development and design of high and extra high voltage apparatus with country's biggest manufacturer. Desires position with large power company. Only position leading to initiative, active and responsible work will be considered. Available on short notice. E-2476.

ELECTRICAL ENGINEER. College graduate 1919, age 24, married. Connection desired with progressive organization preferably west of Chicago, in a sales capacity leading to the position of sales engineer. Good personality, energetic, resourceful and dependable. Year and one-half experience in manufacture of fractional horse-power motors. Some sales experience. Wishes to make connections where unlimited opportunities are afforded. References furnished upon request. E-2477.

MECHANICAL AND ELECTRICAL engineer who has had director of all engineering activities in large industrial organization desires executive position. Has had wide experience in the technical and commercial sides of machinery, manufacture and general production. Has had experience in

power generation and distribution. Has had considerable experience in commercial engineering development with metallurgical and electrochemical industries. E-2478.

ELECTRICAL ENGINEER, graduate of the University of Pennsylvania desires responsible position in the design, construction or maintenance of central and substations. Experienced substation operator anddesigner. Employed at present by prominent consulting power plant engineer for two years. First Lieutenant, Engineer Corps. U. S. Army. Age 30. Single, good executive, good personality. E-2480.

GRADUATE ENGINEER, desires opportunity to learn and grow up with rapidly expanding business, preferably as assistant to production manager. 5½ years general experience, including public utility appraisal, building maintenance and experimental work and supervising design on machine tools. Location preferred New York City or vicinity of Albany, N. Y. E-2479.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Leo Arany, Room 201 Parkway Bldg., Broad & Cherry Sts., Philadelphia, Pa.

2.—James Elliott, Electric Controller & Mfg. Co., Oliver Bldg. Pittsburg, Pa.

3.—Wilfred Langille, Marion Station Public Service Electric Co., Jersey City, N. J.

4.—H. S. Logan, 215-15th Street, Seattle Wash.

5.—Leonard Morey, 1067 East 153rd Street, Cleveland, Ohio

6.—P. J. Reese, 7th & Main Street, Royal Oak, Mich.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED, DECEMBER 10, 1920

ADAIR, SAMUEL E., Electrical Engineer, 1376 Ogden Ave., New York, N. Y.

AMES, ROBERT P., Testing Motors, Century Electric Co., 1827 Pine St.; res., 2608 Locust St., St. Louis, Mo.

ARCHIABLE, GEORGE W., President & General Manager, The Archiable Electric Co., 138 W. 3rd St., Cincinnati, Ohio.

ARNOLD, WILLIAM E., Chief Electrician, Hamilton Woolen Co., Southbridge, Mass.

AYLIFFE, HAROLD E., Head Motor Tester, Century Electric Co.; res., 5841a N. Market St., St. Louis, Mo.

BAKESEF, SAMUEL, Electrical & Mechanical Engineer, 4461 Crocker St., Los Angeles, Cal.

BANGRATZ, ERNEST G., Asst. Electrical Engineer, Jackson & Moreland; res., 19 Hemenway St., Boston, Mass.

BARNETT, BRINKLEY, Asst. Professor of Electrical Engineering Mechanical Hall, University of Kentucky, Lexington, Ky.

BAUER, MILTON EARL, Electrical Testing, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 602 Mulberry St., Wilkinsburg, Pa.

BEREGH, THEODORE J., Electrical Contractor, 461 8th Ave., New York, N. Y.

BLAISDELL, LEONARD T., Manager, General Electric Co., Commercial National Bank Bldg., Washington, D. C.

BOLICK, CLARENCE P., Tester, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 818 Holland Ave., Wilkinsburg, Pa.

BORING, MAYNARD M., Asst. General Foreman, Test Dept., General Electric Co., Schenectady, N. Y.

*BOTTIMER, GORDON W., Switchboard Engineering Dept., General Electric Co.; res., 306 Campbell Ave., Schenectady, N. Y.

BRENNAN, GERARD, Laboratory Asst., New York Edison Co., 92 Vandam St.; res., 51 Bradhurst Ave., New York, N. Y.

BROWN, PLINEY B., Supt., Power House, Sanitary District, Lockport, Ill.; res., Joliet, Ill.

BRUBAKER, HENRY W., General Supt., Edison Electric Co., Conestoga, Bldg., Lancaster, Pa.

BUTTNER, HAROLD H., Asst. Electrical Engineer, Lafayette Radio Station, 8 Rue Colmar, Bordeaux, France.

CAREY, THOMAS E., Assignment Man, Mountain States Tel. & Tel. Co., 1175 Osage Ave., Denver, Colo.

CARISS, CARINGTON C., Estimating Engineer, Waterous Engine Works Co., Ltd.; res., 95 William St., Brantford, Ont.

CASTELLS, ARMANDO, Test Dept., General Electric Co., P. O. Box 871, Schenectady, N. Y.

CHENEY, STUART K., Demonstrator, Electrical Engineering Dept., University of Toronto; res., 127 Givens St., Toronto, Ont.

CUDDY, EDWARD M., Manager, Electrical Dept., Syracuse Supply Co., 314 W. Fayette St., Syracuse, N. Y.

CURRIN, ROBERT H., Electrician, Sanders Electrical Co., 425 Stark St., Portland, Ore.

DOI, MASAJI, Electrical Engineer, Mitsubishi Mining Co., Mitsubishi Namazuta Colliery, Fukuokaken, Japan.

ELLIOTT, JOHN S., Manager, Coto-Coil Co., 87 Willard Ave., Providence, R. I.

ELSBERRY, ARTHUR D., Commercial Engineer, The Union Gas & Electric Co., 4th & Plum Sts., Cincinnati, Ohio.

EVANS, A. EMERSON, Engineering Asst., Bell Telephone Co. of Pennsylvania; res., 149 Hansberry St., Germantown, Philadelphia, Pa.

FEINSILBER, MURRAY, Power Plant Designer, T. E. Murray Co. Inc., 55 Duane St.; res. 830 E. 170th St., New York, N. Y.

FENDRICH, WILLIAM, Jr., Electrical Inspector, U. S. Navy, 44 Court St., Brooklyn, N. Y.; res., 530 Upper Mountain Ave., Upper Montclair, N. J.

FERGUSON, D. C., Chief Draftsman, Beattie McIntyre, Ltd. 72 Victoria St.; res. 2274 Queen St. East, Toronto, Ont.

FLAKE, G. RAYMOND, Chief Electrician, Standard Steel Works Co., Burnham, Pa.

FLYNN, CHARLES C., Electrical Engineering Dept., Ford Motor Co.; res., 2940 E. Grand Blvd., Detroit, Mich.

FOLEY, JAMES J., President & General Manager, Buckeye Equipment Co., 26 W. 3rd St., Cincinnati, Ohio.

FURUKAWA, YOSHIKICHI, Director & Chief Engineer, Kyusuhu Electric Light & Traction Co., Fukuoka, Japan.

GARNER, CLARENCE L., Wire Chief, Washington Coast Utilities, Portage, Wash.

GEALY, EDGAR J., Asst. Electrical Engineer, Lehigh Valley Coal Co., Wilkes-Barre; res., 222 Pierce St., Kingston, Pa.

GEYER, DELBERT G., Asst. Manager, Electrical Dept., Syracuse Supply Co.; res., 412 Stinard Ave., Syracuse, N. Y.

GRAHAM, GEORGE A., Electrical Engineer, Signal Corps, U. S. Army, 1710 Penn. Ave., N. W., Washington, D. C.; res., Baltimore, Md.

GRAVES, ELWOOD L., Instructor, Bliss Electrical School, Washington, D. C.

GREEN, JOHN C., Engineer Inspector, The B. F. Goodrich Rubber Co.; res., 200 W. Chestnut St., Akron, Ohio.

*GUARD, JAMES R., Erecting Engineer, General Electric Co., Witherspoon Bldg., Philadelphia, Pa.

GUHA, DEVENDRA N., President, Hindusthan Electric Co., Calcutta, India.

HACKING, JOHN, Electrical Engineer, Merz. & McLellan, V. Gomez 2807, Buenos Aires, A. R.

*HAMMOND, JACKSON A., Sales Engineer, Westinghouse Elec. & Mfg. Co., 502 Law & Commerce Bldg., Bluefield, W. Va.

HATTORI, KATSUO, Engineer, Shibaura Engineering Works, Kanasugi, Shiba, Tokyo, Japan.

HAYASHI, SEIICHIRO, Electrical Engineer, Furukawa & Co. Ltd., Marunouchi, Tokio, Japan.

HEADINGS, WILLIAM W., Chief Engineer, Carballoy Products Co.; res., 512 Castalia St., Bellevue, Ohio.

HEINZERLING, THEODORE W., Partner, Firm of Bennett & Heinzerling; res., 5720 6th Ave., Brooklyn, N. Y.

HENDRIXSON, BURTON C., Sales Engineer, Buckeye Equipment Co., 26 W. 3rd St., Cincinnati, Ohio.

HENNINGER, ALAN E., Testing Dept., General Electric Co., P. O. Box 609, Schenectady, N. Y.

HOEFER, FRED S., Instructor, Electrical Engineering Dept., Cornell University; res., 200 Willard Ave., Ithaca, N. Y.

HOLROYD, GEORGE E., Foreman, Electrical Dept., Swift & Co.; res., 820 E. 64th St., Chicago, Ill.

HORN, ALBERT F. E., Salesman, General Electric Co., Commercial National Bank Bldg., Washington, D. C.

HUGHES, HAROLD S., Electrical Dept., Q. M. C., U. S. A., Camp Signal Office, Camp Funston, Kansas.

HUSTON, ELBERT L., Commercial Engineer, Union Gas & Electric Co., Cincinnati, Ohio.

HUTH, EDWIN C., Sales Engineer, Century Electric Co., 710 Traction Bldg., Cincinnati, Ohio.

IMAI, MASAKAZU, Chief Electrical Engineer, South Manchurian Railway Co., Darien, Manchuria.

ISONO, TATSUICHIRO, Engineer, Shibaura Engineering Works, Kanasugi, Shiba, Tokyo, Japan.

JOHNSON, FREDERICK H., Laboratory Tester, Standards Laboratory, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

JOHNSON, JAMES A., Supt., Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont.

JONES, ROY S., Electrical Engineer, British Thomson-Houston Co.; res., 131 Murray Road, Rugby, England.

KEETCH, HARRY L., Works Manager's Dept., National Carbon Co., Cleveland; res., 1193 Cranford Ave., Lakewood, Ohio.

KELLY, JOHN E., Secretary, The Southland Products Co., Inc., Humboldt, Tenn.

KELLY, JOSEPH W., Supt., Municipal Light & Water Plant, Algona, Iowa.

KENNEDY, JAMES E., Asst. Division Supt., Southern Power Co., Great Falls, S. C.

KER, MONTGOMERY, Electrical Engineer, The Worcester Woolen Mill Co., Southgate Place; res., 11 Crown St., Worcester, Mass.

KINDY, WARD B., Instructor, Electrical Engineering Dept., Iowa State College, Ames, Ia.

KOMARU, TODA, Electrical Engineer, Mitsubishi Zosen Kabushiki Kaisha Electrical Works, Kobe, Japan.

KONZE, JOHN E., General Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 415 Kelly St., Wilkinsburg, Pa.

KRAFT, AUGUST C., Engineer, Humble Oil & Refining Co., Houston, Texas.

KUHL, FRANK, Electrical Engineer, Pratt Engineering & Machine Co.; res., 422 E. 81st St., New York, N. Y.

LEWIS, WILLIAM G., Power Engineer, Knowlton Bros. Paper Co., Inc., Watertown, N. Y.

LINDSTROM, NILS O., Works Manager, Pacific Ave. & Forest St., Jersey City; res., 121 High St., Nutley, N. J.

LORD, LESLIE MOLINEAUX, 2nd Asst. Electrician, S. S. Leviathan, Hoboken, N. J.

LYDALL, CHAS. H., Electrical Engineer, Merz & McLellan, V. Gomez 2807, Buenos Aires, A. R.

MACDONALD, C. HOLMES, Sr., Engineering Assistant, Bell Telephone Company of Pennsylvania, 19 S. 2nd St., Harrisburg, Pa.

MANDEVILLE, FRANCIS T., Shift Engineer, Radio Corp. of America, Radio Station, New Brunswick, N. J.

MASON, LAVATER W., Meter Tester, Fall River Electric Light Co.; res., 380 Bradford Ave., Fall River, Mass.

McCALL, MALCOLM, Asst. Engineer to Consulting Engineer, The United Light & Power System, Abilene, Kan.

McCOY, JAMES L., Traffic Engineer, Bell Telephone Company of Pa., 253 N. Broad St., Philadelphia, Pa.

McDUFFEE, EARL L., Draftsman, Lockwood, Greene & Co., 822 Book Bldg., Detroit, Mich.

McINTYRE, A. B., Motor Testing, Century Electric Mfg. Co.; res., 4114A Grove St., St. Louis, Mo.

MEYERHOFF, LOUIS, Asst. Electrical Engineer, Crown Cork & Seal Co.; res., 2309 Druid Hill Ave., Baltimore, Md.

*MICHELL, HUMFREY G., Test & Inspecting Engineer, City of Winnipeg Light & Power Dept.; res., 314 Maryland St., Winnipeg, Manitoba.

MILLER, HERBERT E., Asst. Chief Electrician, Pullman Car Co., Pullman, Ill.

MILLS, EDWIN S., Division Foreman, Electrical Dept., Pacific Electric Railway, Los Angeles; res., 1544 3rd St., Santa Monica, Cal.

MONESMITH, ERLE R., Asst. Instructor, Machine Laboratory, Bliss Electrical School, Washington, D. C.

MOORE, EARL S., Sales Engineer, Century Electric Co., 1827 Pine St., St. Louis, Mo.

MORAVECKY, FRANK J., Draftsman, Westinghouse Elec. & Mfg. Co.; res., 6601 Hedge St., Pittsburgh E. E., Pa.

NAVARRO, JUSTO LOPEZ, Electrical Engineer, Philippine Engineering Company, Manila, P. I.

NICHOLSON, ARTHUR T., Salesman, Syracuse Supply Co.; res., 342 Emma St., Syracuse, N. Y.

NORREGAARD, HANS J., Draftsman, New York Edison Co.; res., 3675 Broadway, Apt. 9, New York, N. Y.

OATES, EARL STANLEY, Electrical Engineer, Stone & Webster, Inc.; res., 2007 Diamond St., Philadelphia, Pa.

O'BRIEN, WM. L., Motor Testing, Century Elec. Mfg. Co.; res., 4167 Castleman Ave., St. Louis, Mo.

O'DONNELL, HAROLD L., Supervisor in Army Electrical School, Camp Grant, Ill.

OKADA, HISASHI, Engineer, Shibaura Engineering Works, Kanasugi, Shiba, Tokyo, Japan.

PETERSON, CHESTER A., Tester (Electrician), Safety Insulated Wire & Cable Co.; res., 83 W. 11th St., Bayonne, N. J.

PHILLIPS, LESLIE, Assistant Engineer, Stone & Webster, Boston; res., 33 Grove St., W. Lynn, Mass.

PICKENS, J. FENTON, Asst. Instructor in Electrical Tests, Bliss Electrical School, Washington, D. C.

PIERCE, LEWIS E., Field Engineer, New England Tel. & Tel. Co., 26 Mechanic St., Worcester, Mass.

PITMAN, IRVING G., Instrument Inspector, New York Edison Co., 92 Vandam St., New York; res., 345 Washington St., Newark, N. J.

PRICE, RALPH F., Industrial Engineer, Century Electric Co.; res., 3800 4th St., Des Moines, Iowa.

RANKIN, HARRY M., Lighting Dept., General Electric Co., Schenectady, N. Y.

RAYMOND, CHESTER A., Instructor, Wiring & Meter Testing Dept., Bliss Electrical School, Washington, D. C.

RICE, FRANKLIN S., Engineer, Operating Dept., Great Northern Power Co., Duluth, Minn.

ROCHE, THOMAS F., Electrical Instructor, State Trade School, Putnam, Conn.; 143 Eagle St., North Adams, Mass.

ROMZICK, LAWRENCE H., Electrical Draftsman, Lockwood, Greene & Co., 822 Book Bldg., Detroit, Mich.

RYPINSKI, CHANDOS A., Electrical Draftsman, Engineering Division, Otis Elevator Co.; res., 550 W. 172nd St., New York, N. Y.

SCHACHTE, WILLIAM L., Transformer Engineer, General Electric Co.; res., 68 Northumberland Road, Pittsfield, Mass.

SCHUBERT, WALTER C., Asst. Chief Electrician, Ajax Rubber Co.; res., 2349 Hanson Ave., Racine, Wis.

SCOTT, RALPH Y., Engineer, New England Tel. & Tel. Co., Room 808-50 Oliver St., Boston, Mass.

SEARING, HUDSON R., Radio Engineer, U. S. Army Air Service, Aviation General Supply Depot, Fairfield, Ohio.

SMITH, DAVID D., Motor Tester, Century Electric Company; res., 5252 Paulian Pl., St. Louis, Mo.

SMITS, THEODORE A., Instructor in Physics, University of Pennsylvania, Philadelphia, Pa.

*SONNEBORN, DAVID B., Sales & Prod. Manager, Voltamp Electric Mfg. Co., & Chloride of Silver Dry Cell Battery Co. 407-409 N. Paca St., Baltimore, Md.

STEVENSON, H. A., District Manager, Allen-Bradley Co.' 1115 Citizens Bldg., Cleveland, Ohio.

STONE, ELLERY W., General Manager, Pacific Radio Supplies Co., 638 Mission St., San Francisco, Cal.

STRATTON, D. R., Electrician, Hydro Electric Sta., Winnipeg Electric Railway Co., Pinawa, Man., Can.

SULLIVAN, JAMES D., Chief Electrician, Ray Consolidated Copper Co., Box 625, Hayden Ariz.

SWENSON, LEON G., Chief Electrician, Worcester Gas Light Co., Worcester; res., Oak St., Shrewsbury, Mass.

TENNYSON, ALFRED L., Demonstrator, Electrical Engineering Dept., University of Toronto, Toronto; res., Port Perry, Ont.

TREWMAN, HARRY F., Chief Instructor of Electrical Engineering, Ordnance College, Woolwich, London, Eng.

TRIMMING, PERCY H., Chief Electrician, Dominion Flour Mills, Ltd., Montreal; res., 670 Joseph St., Verdun, Montreal, P. Q.

WAINWRIGHT, EARL M., Electrical Construction, E. I. Du Pont Co. Dye Works, Deepwater Point; res., 70 Penn. St., Penns Grove, N. J.

WANG, HAN CHEN, Student, Harvard University; res., 32 Gorham St., Cambridge, Mass.

WANGMAN, ARTHUR R., Electrical Engineering Dept., Lockwood, Greene & Co.; res., 8658 Epworth Blvd., Detroit, Mich.

WEBBER, GEORGE, E. F., Electrical Engineer, Merz & McLellan, V. Gomez 2807, Buenos Aires, A. R.

WEBSTER, ALFRED F., Jr., Chief Electrician, Crown Cork & Seal Co.; res., 118 S. 5th St., South Baltimore, Md.

WEBSTER, WALTER L., Electrical Engineer, Lockwood, Greene & Co.; res., 882 Manistique Ave., Detroit, Mich.

WHITE, GEORGE P., Engineering Work, American Tel. & Tel. Co., 500 Stahlman Bldg., Nashville, Tenn.

WOODRUFF, L. F. 2nd, Test Man, General Electric Co., Schenectady, N. Y.

WRESSELL, EDMUND F., Chief Electrician, Mechanical & Electrical Dept., Iowa Railway & Light Co., Cedar Rapids, Iowa.

WUNDER, EUGENE G., Fieldman, The Pacific Tel. & Tel. Co., 1102 Telephone Bldg., Portland, Ore.

ZANGLER, HERBERT, Erecting Engineer, Construction Dept., General Electric Co., Schenectady; res., Croton-on-Hudson, N. Y.

ZEHRING, RAYMOND W., Northwest Representative Habirshaw Electric Cable Co.; res., 5003 18th N. E., Seattle, Wash.

*Former enrolled students.
Total 136.

ASSOCIATES REELECTED DECEMBER 10, 1920

BEAUCHAMP, LEON, Manager, & Elec. Engr., Standard Construction Co., Montreal Que.

VATTER, WILBUR L., Division Supervisor of Equipment, Western Union Telegraph Co., 302 Broadway, New York, N. Y.

MEMBERS ELECTED DECEMBER 10, 1920

ADAMS, WILLARD C., Electrical Engineer, Allen & Garcia, 21 East Van Buren St., Chicago, Ill.

AVERY, WILLIAM Y., Sales Engineer, Electro-Dynamic Co., Bayonne; res., 9 Washington Place, Cranford, N. J.

STOFFLET, HOWARD A., Motive Dept., Philadelphia & Reading Railway Co., Reading, Pa.

TRANSFERRED TO GRADE OF MEMBER DECEMBER 10, 1920

BENJAMIN, REUBEN B., President, Benjamin Electric Mfg. Co., Chicago, Ill.

BILLIP, ERNEST H., Partner with J. J. Naugle, New York, N. Y.

BOVEE, BENEDICT A., Professor of Experimental Electrical Engineering, School of Engineering, Milwaukee, Wis.

BRADEN, NORMAN S., Vice-President, Canadian Westinghouse Co. Ltd., Hamilton, Canada.

BUCHANAN, EDWARD V., General Manager, Public Utilities Commission, London, Ontario.

CARLSON, FREDERICK, W., Supt. of Electrical Dept., Davison Chemical Co., Curtis Bay, Md.

ELLIOTT, LOUIS, Steam Plant Engineer, Electric Bond & Share Co., New York, N. Y.

FLANDERS, CHARLES K., Captain, Signal Corps, U. S. A. New York, N. Y.

GARLINGTON, A. C., Supt. of Construction & Maintenance, Elec. Div., Panama Canal, Balboa, C. Z.

GIBBS, GEORGE S., Sales Engineer, Representative, Westinghouse Elec. & Mfg. Co., Boston, Mass.

HERTNER, JOHN, H., President, Hertner Electric Co., Cleveland, O.

NEILD, JAMES F., Supt. of Substations, Toronto Railway Co., Toronto, Ont.

OLSEN, VALDEMAR, Meter Engineer, Shanghai Municipal Council, Electricity Dept., Shanghai, China.

RADBONE, VICTOR, J., Sales Engineer, Int'l General Electric Co., London, England.

ROBERTS, EDWARD A., Engineer, John A. Beeler, New York, N.Y

SCHWARZE, FRED, Electrical Engineer, Pfister & Vogel Leather Co., Milwaukee, Wis.

SHUCK, GORDON R., Instructor in Electrical Engineering, University of Washington, Seattle, Wash.

UPSON, WALTER L., Professor Electrical Engineering, Washington University, St. Louis, Mo.

WOOLHISER, H. L., Business Manager, Village of Winnetka, Winnetka, Ill.

TRANSFERRED TO GRADE OF FELLOW, DECEMBER 10, 1920

BIRD, WILLIAM L., Manager, Secretary, Director, Kaministiquia Power Co., Fort William, Ont.

BRANDON, EDGAR T. J., Electrical Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

MOREHOUSE, LYMAN F., Equipment Development Engineer, American Telephone & Telegraph Co., New York, N. Y.

WYNNE, FRANCIS E., Manager, Railway Equipment Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held November 29, 1920, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

GRAY, GEORGE F., Assistant Manager, Engineering Dept., National Analine & Chemical Co., New York, N. Y.

HAZELTINE, LOUIS A., Professor of Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.

OSBORNE, HAROLD S., Transmission Engineer, American Telephone & Telegraph Co., New York, N. Y.

WATER, GRANVILLE A., Assistant Chief Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.

WOODBRIDGE, J. LESTER, Chief Engineer, Electric Storage Battery Co., Philadelphia, Pa.

To Grade of Member

APPLEYARD, ARTHUR E., Manager, Minneapolis Anoka & Cuyuna Range Ry. Co.; President, British Columbia & Alberta Power Co. Ltd.; Minneapolis, Minn.

BARNS, BIRD L., A. C. Engineer, Canadian General Electric Co., Peterborough, Ont.

BERNHARD, FRANK H., Editor, E. M. F. Electrical Year Book, Electrical Trade Publishing Co., Chicago, Ill.

CARPENTER, HENRY C., Chief Engineer, New York Telephone Co., New York, N. Y.

EVANS, PORTER H., Engineering Dept., Western Electric Co., New York, N. Y.

FECHT, ARTHUR J., Associate Electrical Engineer, Bureau of Standards, Washington, D. C.

GROSS, BENJAMIN, Chief Engineer, Hatzel & Buehler, Inc., New York, N. Y.

HANNAFORD, FOSTER, General Manager, Twin City Rapid Transit Co., Minneapolis, Minn.

HERRMANN, RAYMOND R., Instructor in Mathematics and Mechanics, University of Minnesota, Minneapolis, Minn.

LEE, CARL, Electrical Engineer, Peabody Coal Co., Chicago, Ill.

PETTY, EDWIN W., Electrical Engineer, H. M. Byllesby Co., Chicago, Ill.

POMEROY, WILLIAM D., Vice-President and General Manager, Goulds Manufacturing Co., Seneca Falls, N. Y.

POOL, RALPH Y., General Superintendent, Intermountain Railway Light & Power Co., Colorado Springs, Colo.

STICKNEY, H. RUSSELL, Electrical Engineer, Jackson & Moreland Boston, Mass.

STOKES, STANLEY, General Supt. Outlying Plants, Union Electric Light & Power Co.; Vice-President & General Manager, Commercial Telephone Co.; St. Louis, Mo.

WHALEN, JAMES M., Vice-President & Manager of Machine Dept., Northwestern Electric Equipment Co., St. Paul, Minn.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member, objecting to the election of any of these candidates should so inform the Secretary before January 31, 1920.

Allen, Alex. D., Hamilton, Ont.
Ayles, Jesse A., Boston, Mass.
Beedle, A. L., Cincinnati, Ohio.
Behner, Leroy, Pittsburgh, Pa.
Behnke, R. E., New York, N. Y.
Berton, Philip L., Montreal, Que.
Blaisdell, Colborn E., Dover, N. H.
Bliss, Ernest F., East Moriches, L. I., N. Y.
Bodicky, Andrew, St. Louis, Mo.
Boyer, William H., Portland, Ore.
Bright, Jacob, Philadelphia, Pa.
Brown, Ellsworth A., Syracuse, N. Y.
Bruns, Harry, New York, N. Y.
Calhoun, Ernest N., Milwaukee, Wis.
Capwell, Elmer A., Anthony, R. I.
Carrothers, John W., Kansas City, Mo.
Carter, Philip S., New York, N. Y.
Casselberry, Charles L., Syracuse, N. Y.
Clements, William R., (Member), Dayton, Ohio.
Cogan, Nyles M., Boston, Mass.
Cook, Querin H., Chicago, Ill.
Cotterman, Leo K., Manila, P. I.
Cotting, Paul M., Boston, Mass.
Cowie, Hugh, Peterboro, Ont.
Cronkite, Minton, New York, N. Y.
Darling, John A., Schenectady, N. Y.
Davis, R. J., St. Louis, Mo.
Degnan, Robert E., New York, N. Y.
Dickinson, Wilbur K., Lynn, Mass.
Dole, Sanford B., San Francisco, Cal.
Dunkle, Clarence C., Kellogg, Idaho.
Dyer, John B., (Member), Ferguson, Mo.
Elliot, Andrew H., Montreal River, Ont.
Engle, Melvin D., Baltimore, Md.
Euston, Jacob H., Ann Arbor, Mich.
Fairlie, Howard W., Montreal, Que.
Fariss, T. McL., St. Louis, Mo.
Ferguson, John R., New York, N. Y.
Ferlic, Andrew J., E. Pittsburgh, Pa.
Fonseca, Arthur W., Portland, Ore.
Fonsica, Edward L., Newark, N. J.
Fraser, William W., Schenectady, N. Y.
Gardner, William G., Philadelphia, Pa.
Gavin, Robert G., Montreal, Que.
George, Beauford J., Kansas City, Mo.
George, R. B., Agricultural College, Miss.
Gilbert, Frederick W., Schumacher, Ont.
Gillmore, Reginald W., W. Lynn, Mass.
Gilt, Carl M., Schenectady, N. Y.
Glennie, Alfred G., Hartford, Conn.
Goljenboom, George, Milwaukee, Wis.
Goodale, Josiah E., Long Island City, N. Y.
Gray, Cecil, Baltimore, Md.
Griest, George W., Lancaster, Pa.
Griffin, John F., Valparaiso, Ind.
Grush, Henry G., Boston, Mass.
Hackett, J. Henry, Philadelphia, Pa.
Hackett, John W., New York, N. Y.
Haislip, Richard A., New York, N. Y.
Hallett, William S., Cobalt, Ont.
Hammerton, William G., Toronto, Ont.
Harrison, John A., (Member), Lima, Ohio.
Hawley, Howard B., Cobalt, Ont.
Hawthorne, Jack A., New York, N. Y.
Healey, Rolla E., Boston, Mass.
Heidenrich, George E., Cleveland, Ohio.
Heinemann, J. Robert, Schenectady, N. Y.
Hill, Walter L., San Jose, Cal.
Hollender, William, Brooklyn, N. Y.
Howard, James P., Winnipeg, Manitoba.
Hudson, Walter F., Utica, N. Y.
Hymes, Harry, E. Pittsburgh, Pa.
Isley, Cary T., Wadesboro, N. C.
Jacobs, Arthur R., Chicago, Ill.
James, Carl P., Philadelphia, Pa.
Johnson, Herbert M., Worcester, Mass.
Jones, Gerald L., Peterboro, Ont.
Jones, Herndon C., Hollidays Cove, W. Va.
Jones, Julian D., Philadelphia, Pa.
Jones, William S., Washington, D. C.
Kalbach, Stanley M., (Fellow), Baltimore, Md.
Kapp, Cecil A., Atlanta, Ga.
Keeley, Henry J., Denver, Colo.
Kennedy, Thomas W., Schenectady, N. Y.
Kinley, Clifford B., Toledo, Ohio.
Klingman, Loren E., Ft. Wayne, Ind.
Krouss, William A., Pittsburgh, Pa.
Lake, Charles J., Philadelphia, Pa.
Lemmon, Walter S., New York, N. Y.
Lemon, Alonzo L., Schenectady, N. Y.
Leonard, William E., Boston, Mass.
Loewenthal, George G., Pueblo, Colo.
Long, Ralph E., E. Pittsburgh, Pa.
Loughead, Robert C., Detroit, Mich.
Lowcook, Henry, Milwaukee, Wis.
Lueking, Lancelot L., St. Louis, Mo.
Luenebrink, Chester F., St. Louis, Mo.
Luney, Oswald S., Niagara Falls, Ont.
Lynde, Walter L., Beaver Dam, Ohio.
MacDonald, Russell, Philadelphia, Pa.
Marsh, E. L., Schenectady, N. Y.
Marson, Arnaldo, New York, N. Y.
Mason, Roy W., Pittsfield, Mass.
Matthews, Charles H., (Member), Cleveland, Ohio.
Mayer, George H., Stevens Point, Wis.
Miles, Frank T., Indianapolis, Ind.
Milford, William J., Tacoma, Wash.
Miller, LeRoy J., Brooklyn, N. Y.
Moore, Ernest R., Boston, Mass.
Moore, Harold S., Schenectady, N. Y.
Moore, Willard S., New York, N. Y.
Munro, Peter B., Peterboro, Ont.
Murray, Edwin R., San Francisco, Cal.
McDonald, Gordon R., Schenectady, N. Y.
McDonald, John A., Salt Lake City, Utah.
McEver, William L., Atlanta, Ga.
McFerrin, Albert B., St. Louis, Mo.
McGill, Charles S., Wilmington, Del.
McKamy, W. E., Atlanta, Ga.
McWilliam, Cecil E., Peterboro, Ont.
Nelson, Rufus L., Utica, N. Y.
Neumann, Warren R., Lawrence, Kans.
Noddins, Raymond W., Orleans, Mich.
Ostrall, Harry, Brooklyn, N. Y.
Papineau, Denis V., Outremont, P. Q.
Peterson, Paul, Scranton, Pa.
Phillips, Leon L., Portland, Ore.
Pomares, Marino L., Long Island City, N. Y.
Pullman, William, (Member), Westend, Cal.

Rainey, Punderson A., Philadelphia, Pa.
Randa, Charles E., Hawthorne, Ill.
Ransom, Paul, Bingham Canyon, Utah.
Reeder, Claude H., Chicago, Ill.
Reid, John H., Peterboro, Ont.
Sandalls, George, Jr., New York, N. Y.
Sander, Theodore, Jr., St. Paul, Minn.
Savage, Marion A., Schenectady, N. Y.
Schief, Eugene R., Brooklyn, N. Y.
Schlesinger, Oscar A., San Francisco, Cal.
Schmidt, Clarence W., Milwaukee, Wis.
Scott, John D., Portland, Ore.
Shand, Fred B., Toronto, Ont.
Shapiro, Louis, New York, N. Y.
Siegel, Robert C., Madison, Wis.
Simon, Le Roy, Baldwin, N. Y.
Simons, James A., Milwaukee, Wis.
Spangler, William N., Philadelphia, Pa.
Spencer, T. Harold, Springfield, Mass.
Stanford, Alan G., Atlanta, Ga.
Stebbins, Duton L., Spokane, Wash.
Stederoth, Frederick F., Jersey City, N. J.
Stephens, Herbert C., Cleveland, Ohio.
Strobel, William F., Brooklyn, N. Y.
Surprise, Edwin M., (Member), Boston, Mass.
Swenson, Ivar A., Boston, Mass.
Thickman, Bernard, New York, N. Y.
Thomas, Charles M., Fall River, Mass.
Thomson, Harry L., Hartford, Conn.
Thrailkill, W. Louis, Bremerton, Wash.
Toregsen, Torris K., (Member), New York, N. Y.
Towne, Walter I., Boston, Mass.
Turner, Harrison I., Boston, Mass.
Underhill, George H., Poughkeepsie, N. Y.
Walker, Robert L., Atlanta, Ga.
Wallace, Gordon S., Boston, Mass.
Walsh, James A., New York, N. Y.
Walton, Albert S., Elkton, Md.
Whorf, Edward W., Boston, Mass.
Wilburn, Sidney D., St. Louis, Mo.
Wilkinson, Reading, Birmingham, Ala.
Wilson, Leonard B., Cobalt, Ont.
Wiltse, Stanley B., Troy, N. Y.
Wolferz, Alfred H., Newark, N. J.
Wolfinger, Wesley C., E. Pittsburgh, Pa.
Woxman, Carl A., Dayton, Ohio.
Wright, George P., Nashville, Tenn.
Total 176.

Foreign

Baker, Harry D., Cristobal, C. Z.
Battye, Basil C., (Member), Punjab, India.
Dick, Walter R. H., (Member), London, Eng.
Guha, Surendra K., Jamshedpur, India.
Gupta, Amullya R., Jamshedpur, India
Herd, Philip, (Member), Johannesburg, S. Africa.
Kamai, Daizo, Jitachiseisakusho, Sikehaweeki, Ibaragiken,Japan
Palmer, Charles R., Calcutta, India.
Sales, Harold B., Buenos Aires, Argentine, S. A.
Stuart, James E. B., Balboa Heights, C. Z.
Tanaka, M., Tokio, Japan.
Tatebe, Teiji, Tokyo, Japan.
Thoresen, Jetmund J., (Fellow), Kristiania, Norway.
Total 13

Supplementary List

Adams, Allen A., Los Angeles, Cal.
Alexander, Peter P., Lynn, Mass.
Allen, Charles S., Phillipsburg, N. J.
Allen, John E., Baltimore, Me.
Apostolon, James, E. Pittsburgh, Pa.
Barnes, Irving T., Boston, Mass.
Biggers, Jesse D., Norman, Okla.
Bloss, Ernest K., Pittsburgh, Pa.
Blumberg, Leo, Newark, Del.
Bocher, Herman W., Jr., Milwaukee, Wis.
Boody, Percy L., Minneapolis, Minn.
Boothroyd, Claude O., Syracuse, N. Y.
Brown, John D., Bridgeport, Conn.
Brown, William J., Atlanta, Ga.
Brush, Charles F., Jr., Cleveland, Ohio
Cannon, William D., Urbana, Ill.
Carrow, Harold G., Lansing, Mich.
Chadwick, Wallace L., Cartago, Inyo Co., Cal.
Chelton, Henry C., Baltimore, Md.
Churchland, John, Vancouver, B. C.
Clark, Harold B., (Member), New Haven, Conn.
Croly, Robert M., New York, N. Y.
Cross, Charles H., Solvay, N. Y.
Dennison, Kenneth R., Toronto, Ont.
Cunningham, Paul D., Atlanta, Ga.
Davis, Robert L., Kingston, Ont.
Dawson, Hilarion D., Springfield, Mass.
Elligers, Johan, Phoenix, Ariz.
Ellinwood, Ralph W., Boston, Mass.
English, G. H., Philadelphia, Pa.
Estes, Marion S., Denver, Colo.
Flockard, Derwent P., Pittsburgh, Pa.
Fryer, Roy C., Cincinnati, Ohio
Fujimoto, Tadashi, Middletown, Conn.
Garwin, Robert, Cleveland, Ohio
Germain, Leon W., Chicago, Ill.
Gish, Henry J., St. Joseph, Mo.
Grady, James M., New York, N. Y.
Grebel, Vilar E., Green Bay, Wis.
Hartman, Elmer E., (Member), Sugar Creek, Mo.
Hawley, Dexter R., Boston, Mass.
Hawlk, Cheston R., Philadelphia, Pa.
Hubbard, Fred W., Pittsburgh, Pa.
Huey, Raymond W., Atlanta, Ga.
Humphrey, Charles G., New York, N. Y.
Jemmett, Douglas M., Kingston, Ont.
Kinnard, Isaac F., E. Pittsburgh, Pa.
Klass, Fred, Schenectady, N. Y.
Lang, Edward H., Pittsburgh, Pa.
Lathrop, Willis F., Schenectady, N. Y.
Lawton, Lewis C., Philadelphia, Pa.
Lurie, Sidney J., Chicago, Ill.
Maher, Henry C., New York, N. Y.
Maxwell, Marshall P., New York, N. Y.
Millard, Arthur M., New Haven, Conn.
Milne, Gordon R., Newark, N. J.
Moffitt, L. E., Brooklyn, N. Y.
Mosher, Maurice E., New York, N. Y.
Muller, George G., New York, N. Y.
McGillivray, Harry, New York, N. Y.
Nalle, John M., Elkwood, Va.
Newell, Hobart H., E. Pittsburgh, Pa.
Nottingham, Wilbur F., Duluth, Minn.
Olsen, Richard H., Chicago, Ill.
Orsoe, John J., Perth Amboy, N. J.
Payne, Walter B., Atlanta, Ga.
Peebles, John B., (Member), Emory University, Va.
Pendery, Horace F., Cincinnati, Ohio
Peters, Oscar F., Brooklyn, N. Y.
Quinneen, Charles R., Boston, Mass.
Ralston, Emmet G., Indianapolis, Ind.
Ray, Edward C., (Member), New York, N. Y.

Rockwell, Edward W., Los Angeles, Cal.
Rumford, Frederick J., Boston, Mass.
Schlesinger, Oscar A., San Francisco, Cal.
Setze, Henry R., Atlanta, Ga.
Shouse, Frederick A., Atlanta, Ga.
Smelser, W. A., Vancouver, B. C.
Smith, Nehill F., Troy, N. Y.
Sose, Paul R., Salt Lake City, Utah
Spacshott, Alfred H., Clarendon, Va.
Spargur, Herbert W., Huntington, N. Y.
Stephens, Charles B., Toronto, Ont.
Stone, Howard B., Springfield, Ohio
Thomson, David P., W. Lynn, Mass.
Thomson, Malcolm, Lynn, Mass.
Tikhonovitch, Benedict S., New York, N. Y.
Tucker, Allan W., New York, N. Y.
Vanderhoof, Alex., Newark, N. J.
Vaughan, James W., Jr., Atlanta, Ga.
Vedder, Wilson Y., Schenectady, N. Y.
Vogel, Fred J., E. Pittsburgh, Pa.
Wallerstedt, Carl A., Northampton, Pa.
Webber, Franklin C., Los Angeles, Cal.
Whitmore, Walter, Boston, Mass.
Whitney, Russell L., Wilkinsburg, Pa.
Winegartner, Carl E., Cleveland, Ohio
Winter, Willis L., San Francisco, Cal.
Wohlpat, Joseph P., New York, N. Y.
Yordon, Wesley J., Fulton, N. Y.
Yost, Norman S., Howell, Mich.
Final Total 277

STUDENTS ENROLLED DECEMBER 10, 1920.

12060 Morgenson, Edgar O., Pratt Institute
12061 Hollenback, Frank J., Pratt Institute
12062 Welsome, Peter, Pratt Institute
12063 Partridge, Ralph E., Pratt Institute
12064 Turner, Edmund T., Pratt Institute
12065 Clayton, Albert W., Pratt Institute
12066 Strong, Ray W., Pratt Institute
12067 Huyssoon, Donald J., Pratt Institute
12068 Wolf Ezekiel, Harvard Engineering School
12069 Jedlicka, Theodore E., Pratt Institute
12070 Lutz, William E., Pratt Institute
12071 Peters, James S., Sheffield Scientific School
12072 Lotter, Joseph C., University of Wisconsin
12073 Valverde, Robert, Columbia University
12074 Dennison, Harlan S., University of Maine
12075 Stevenson, William S., University of Maine
12076 Plumer, Wesley C., University of Maine
12077 Giles, Wallace E., Pratt Institute
12078 Lyman, Harry H., Pratt Institute
12079 Keene, Kenneth W., Pratt Institute
12080 Ford, William, New York Electrical School
12081 Johnson, Edward L., Pratt Institute
12082 Bettels, Edward T., Pratt Institute
12083 Taylor, Olaf C., Ohio Northern University
12084 Hand, Harry S., Pratt Institute
12085 Barker, Orlan, Pratt Institute
12086 Gropp, George J., New York Electrical School
12087 Lowe, Harry F., Purdue University
12088 Schwarz, Clarence E., Purdue University
12089 Weber, Clayton J., Purdue University
12090 Vehling, Robert H., Purdue University
12091 Hanna, Clinton R., Purdue University
12092 Granger, Merlin R., Purdue University
12093 Stevenson, William N., Purdue University
12094 Finehout, Frederick R., Purdue University
12095 Hurtt, Robert S., Purdue University
12096 Miller, Harry B., Purdue University
12097 Blake, Joel W., Oklahoma A. & M. College
12098 Joerden, Russell H., University of Arkansas
12099 Johnson, Howard E., Pratt Institute
12100 Ingalls, Darwin A., Oregon Agricultural College
12101 Hood, Harry W., Jr., Clemson Agricultural College
12102 Duckworth, Barksdale F., Clemson Agricultural College
12103 Tuler, Wallace P., Clemson Agricultural College
12104 Hertler, Walter, Drexel Institute
12105 Catchpole, Leslie A., Central Technical School
12106 Kenworthy, Oswald E., Pennsylvania State College
12107 Loucks, Burton H., Jr., Pratt Institute
12108 Wright, Claude B., School of Engineering of Milwaukee
12109 Winship, Alson R., School of Engineering of Milwaukee
12110 Wilson, Don P., School of Engineering of Milwaukee
12111 Whitworth, William E., School of Engineering of Milwaukee
12112 Valentine, Merritt M., School of Engineering of Milwaukee
12113 Ulrey, Edgar L., School of Engineering of Milwaukee
12114 Swanson, Ernest V., School of Engineering of Milwaukee
12115 Spieth, Joseph T., School of Engineering of Milwaukee
12116 Smith, Fred B., School of Engineering of Milwaukee
12117 Smith, Clyde L., School of Engineering of Milwaukee
12118 Slye, M. E., School of Engineering of Milwaukee
12119 Seibold, Raymond W., School of Engineering of Milwauke
12120 Satory, Edward T., School of Engineering of Milwaukee
12121 Rohrer, Philip R., School of Engineering of Milwaukee
12122 Riley, Adolph B., School of Engineering of Milwaukee
12123 Rieck, Irwin J., School of Engineering of Milwaukee
12124 Raddant, Albert W., School of Engineering of Milwaukee
12125 Pokras, Adolph, School of Engineering of Milwaukee
12126 Pobanz, Chauncey J., School of Engineering of Milwaukee
12127 Odell, Clarence E., School of Engineering of Milwaukee
12128 Nitze, Harold R., School of Engineering of Milwaukee
12129 Nicholas, Elbert F., School of Engineering of Milwaukee
12130 Myers, Vincent E., School of Engineering of Milwaukee
12131 Moser, Matthew H., School of Engineering of Milwaukee
12132 Morse, William K., School of Engineering of Milwaukee
12133 McMahan, Rollie, School of Engineering of Milwaukee
12134 McGann, James L., School of Engineering of Milwaukee
12135 Low, Frank K., School of Engineering of Milwaukee
12136 Lehnen, Elmer J., School of Engineering of Milwaukee
12137 Lahym, Ralph W., School of Engineering of Milwaukee
12138 Klessig, Clarence E., School of Engineering of Milwaukee
12139 Kersten, Harold J., School of Engineering of Milwaukee
12140 Keno, Dewey, School of Engineering of Milwaukee
12141 Kelley, Floran S., School of Engineering of Milwaukee
12142 Keen, Royal S., School of Engineering of Milwaukee
12143 Jorgensen, Norman H., School of Engineering of Milwaukee
12144 Jamison, Charles L., School of Engineering of Milwaukee
12145 Hughes, Harry E., School of Engineering of Milwaukee
12146 Helwig, William F., School of Engineering of Milwaukee
12147 Harl, G. P., School of Engineering of Milwaukee
12148 Haines, Chester J., School of Engineering of Milwaukee
12149 Grosso, Peter P., School of Engineering of Milwaukee
12150 Greiner, Harold, School of Engineering of Milwaukee
12151 Greensward, Donald J., School of Engineering of Milwaukee
12152 Goodermote, Edgar J., School of Engineering of Milwaukee
12153 Goetschius, Walter L., School of Engineering of Milwaukee
12154 Gildersleeve, Tuttle S., School of Engineering of Milwaukee
12155 Gibbons, John P., School of Engineering of Milwaukee
12156 Fox, Jerome E., School of Engineering of Milwaukee
12157 Downey, Richard G., School of Engineering of Milwaukee
12158 Davis, Arthur W., School of Engineering of Milwaukee
12159 Curtis, Lyle C., School of Engineering of Milwaukee
12160 Currie, Frank L., School of Engineering of Milwaukee

12161 Cummings, George B., School of Engineering of Milwauke
12162 Cheever, Lyndon L., School of Engineering of Milwaukee
12163 Carlson, George, School of Engineering of Milwaukee
12164 Button, Harry J., School of Engineering of Milwaukee
12165 Bublitz, Zeno P., School of Engineering of Milwaukee
12166 Braam, Alfred E., School of Engineering of Milwaukee
12167 Boettcher, William W., School of Engineering of Milwaukee
12168 Berg, Leo F., School of Engineering of Milwaukee
12169 Barker, Herman H., School of Engineering of Milwaukee
12170 Andrews, Cecil J., School of Engineering of Milwaukee
12171 McIlvaine, Victor C., Alabama Polytechnic Institute
12172 Pulley, Robert L., Alabama Polytechnic Institute
12173 Cooper, Robert J., Alabama Polytechnic Institute
12174 Wade, Allan J., Alabama Polytechnic Institute
12175 Bowne, John H., Alabama Polytechnic Institute
12176 Snuggs, Charles H., Alabama Polytechnic Institute
12177 Porter, Roy T., Alabama Polytechnic Institute
12178 Neely, Thomas, Alabama Polytechnic Institute
12179 Funderburg, Claud H., Alabama Polytechnic Institute
12180 Peterson, Lyman L., Alabama Polytechnic Institute
12181 Hillman, Lyle J., Alabama Polytechnic Institute
12182 Hornsby, Grover J., Alabama Polytechnic Institute
12183 Watson, Luther B., Jr., Alabama Polytechnic Institute
12184 House, Ray W., Alabama Polytechnic Institute
12185 Crane, Lawrence W., Alabama Polytechnic Institute
12186 Looney, John B., Alabama Polytechnic Institute
12187 Bradley, Charles H., Alabama Polytechnic Institute
12188 McCaleb, Thomas S., Catholic University of America
12189 Ege, Howard D., University of Kansas
12190 Sadona, Paul G., Pratt Institute
12191 Morey, Manuel, New York Electrical School
12192 Weaver, Willis, Jr., University of Michigan
12193 Warren Francis C., University of Michigan
12194 Johnston, Franklin D., University of Michigan
12195 Hoyt, Alden G., University of Michigan
12196 Van Volkenburg, Ray, University of Michigan
12197 Trefey, Donald E., University of Michigan
12198 Stratton, Donald B., University of Michigan
12199 Smith, Richard D., University of Michigan
12200 Seeley, Harold C., University of Michigan
12201 Lewis, Dean A., University of Michigan
12202 Cornell, Harold G., University of Michigan
12203 Schlotterbeck, P. G., University of Michigan
12204 Moulton, Bruce S., University of Michigan
12205 Martin, Allen J., University of Michigan
12206 Korten, George E., University of Michigan
12207 Kerolla, Alfred J., University of Michigan
12208 Barker, Donald J., University of Michigan
12209 Halman, Theodore R., University of Michigan
12210 Gosinski, John N., University of Michigan
12211 Goodenow, Reginald M., University of Michigan
12212 Gault, James S., University of Michigan
12213 Foulks, William VanC., University of Michigan
12214 Folsom, Everett W., University of Michigan
12215 De France, Smith J., University of Michigan
12216 Cook, Wilbur E., University of Michigan
12217 Buell, Roy C., University of Michigan
12218 Buchanan, Arthur B., University of Michigan
12219 Bergvall, Royal C., University of Michigan
12220 Remine, Harold H., University of Michigan
12221 Edwards, Kenneth C., Pratt Institute
12222 Wilhelm, Dean M., Carnegie Institute of Technology
12223 Butler, Paul W., Pratt Institute
12224 Muller, John H., Jr., Stevens Institute of Technology
12225 Peacock, Leonard E., A. & M. College of Texas
12226 King, Robert, A. & M. College of Texas
12227 Crawford, Robert W., Cornell University
12228 Levene, Hyman C., Cornell University
12229 Vermilye, Sherwood, Cornell University
12230 McLean, True, Cornell University
12231 Baum, Seymour L., Cornell University
12232 Stemper, Herman, Cooper Union
12233 Jenkins, Hope F., Kansas State Agricultural College
12234 Wells, Harold, Pratt Institute
12235 Mudgett, Guernsey F., Pratt Institute
12236 Pendleton, Lee L., University of Pittsburgh
12237 Bennett, Chester B., University of Pittsburgh
12238 Finerty, John J., University of Pittsburgh
12239 Merritt, Charles W., University of Pittsburgh
12240 Saunders, Charles L., University of Virginia
12241 Sands, George K., University of Virginia
12242 Harris, Henry M., University of Virginia
12243 Gilchrist, William MacN., University of Virginia
12244 Pingree, Herbert B., Pratt Institute
12245 Sheridan, Frank C., Pratt Institute
12246 Pierre, Gerald J., Purdue University
12247 Budenham, Horace T., Purdue University
12248 Sweets, Joseph E., Purdue University
12249 Wintersteen, Herbert P., Purdue University
12250 Fackler, Irving C., School of Engineering of Milwaukee
12251 Groot, Robert W., School of Engineering of Milwaukee
12252 Mackart, Edward T., School of Engineering of Milwaukee
12253 Broadbent, Floyd W., School of Engineering of Milwaukee
12254 Bauer, Conrad, School of Engineering of Milwaukee
12255 Revin, Howard H., School of Engineering of Milwaukee
12256 Ehlert, Otto H., School of Engineering of Milwaukee
12257 Sabatke, Erwin G., School of Engineering of Milwaukee
12258 Radtke, Harold A., School of Engineering of Milwaukee
12259 Oopcensky, Joseph F., School of Engineering of Milwaukee
12260 Lee, Sam, School of Engineering of Milwaukee
12261 Johnson, Kenneth, School of Engineering of Milwaukee
12262 Schulz, Victor, School of Engineering of Milwaukee
12263 Van Orden, Clarence E., Syracuse University
12264 Hanford, Russell, E., Syracuse University
12265 Fugill, Alfred P., Syracuse University
12266 Baker, Ralph H., Syracuse University.
12267 Bentley, Clyde E., University of California
12268 Berry, Harvey R., University of California
12269 Doyle, Franklin B., University of California
12270 Holte, Harold O., University of California
12271 Keith, James N., Jr., University of California
12272 McMurray, Theodore H., University of California
12273 McNaughton, Edward F., University of California
12274 Manildi, Joseph S., University of California
12275 Maybeck, Wallen W., University of California
12276 Meyers, Leslie O., University of California
12277 Morisuye, Masa M., University of California
12278 Reukema, Lester E., University of California
12279 Newton, William E., University of California
12280 Savage, Philip L., University of California
12281 Smith, Harvey L., University of California
12282 Towner, Leonard W., University of California
12283 Pease, Robert M., Pratt Institute
12284 Anthony, Claude E., Pratt Institute
12285 Egan Kyran Wm., University of Kansas
12286 McCall, Dana H., University of Kansas
12287 Baker, Floyd A., California Institute of Technology
12288 Schreiber, Ernst H., California Institute of Technology
12289 Forgy, Edward G., California Institute of Technology
12290 Ogden, Harold S., California Institute of Technology
12291 Garfield, Arthur J., Jr., California Institute of Technology
12292 Ager, Raymond W., California Institute of Technology
12293 Lownes, Edward D., California Institute of Technology
12294 Eckermann, Carlton, H., California Institute of Technology
12295 Walters, Fred W., California Institute of Technology
12296 Webster, Glen M., California Institute of Technology

12297 Scribner, Henry I., California Institute of Technology
12298 Endicott, Harols S., California Institute of Technology
12299 Groat, Edmund, California Institute of Technology
12300 Fleming, Thomas J., California Institute of Technology
12301 Johnson, Frank K., California Institute of Technology
12302 Barnsdale, Garrett H., California Institute of Technology
12303 Chandler, Lawrence F., California Institute of Technology
12304 Hare, Robert J., California Institute of Technology
12305 Wells, Lewis J., California Institute of Technology
12306 Herberger, Arthur L., California Institute of Technology
12307 Honsaker, Horton H., California Institute of Technology
12308 McCrea, Truman F., California Institute of Technology
12309 Learned, Kenneth A., California Institute of Technology
12310 Storms, Charles A., California Institute of Technology
12311 Walter, John P., California Institute of Technology
12312 Ferrell, J. T., Rose Polytechnic Institute
12313 Penna, Clarence I., Rose Polytechnic Institute
12314 Schroeder, Carl W., Rose Polytechnic Institute
12315 Bruning, William H., Rose Polytechnic Institute
12316 Weir, Irvin R., Rose Polytechnic Institute
12317 Minar, Samuel J., Rose Polytechnic Institute
12318 Biller, Ray L., Rose Polytechnic Institute
12319 Bixby, Allan S., Rose Polytechnic Institute
12320 Faucett, Max A., Rose Polytechnic Institute
12321 Moses, Earl, Rose Polytechnic Institute
12322 Dowen, C. J., Jr., Rose Polytechnic Institute
12323 Brown, Thomas F., New York Electrical School
12324 King, Ralph E., University of Iowa
12325 Beyers, Arthur P., University of Iowa
12326 Krause, Charles E., University of Iowa
12327 Artiggs, J. Antonio, Cornell University
12328 Bemus, William J., Cornell University
12329 Bishop, George M., Cornell University
12330 Strack, Ernest V., Cornell University
12331 Carr, Harold F., Cornell University
12332 Ulrich, Francis V., Cornell University
12333 Roth, Eugene D., Cornell University
12334 Blewitt, Harold F., Pennsylvania State College
12335 Dean, Allery L., School of Engineering of Milwaukee
12336 Lannon, John V., Pennsylvania State College
12337 Morrison, Robert D., University of California
12338 Williams, Leicester H., University of California
12339 Lowell Institute, Mass. Inst. of Tech.
12340 Cummings, Edwin W., Drexel Institute
12341 Hobrock, Raymond, Purdue University
12342 Chellew, Edward M., Purdue University
12343 Chou C. Lee, Purdue University
12344 Bolt, Harry E., Purdue University
12345 Harness, George C., Purdue University
12346 Anderson, Carl R., Purdue University
12347 Patterson, Robert J., Purdue University
12348 Leetz, Richard, Purdue University
12349 Schoene, Russell L., Purdue University
12350 Callis, Paul A., Purdue University
12351 Block, J. H., Casino Technical Night School
12352 Pennefeather, Joseph E., Tri-State College
12353 Newmeyer, James H., Ohio Northern University
12354 Crawford, William T., Drexel Institute
12355 Strassburger, Julius H., Stevens Institute of Technology
12356 Koeneman, Egmund A., University of Minnesota
12357 Hughes, Rollin B., University of Minnesota
12358 Lauritzen, Carl W., University of Minnesota
12359 Smith, Harold D., University of Minnesota
12360 Case, Gerald F., University of Minnesota
12361 Wilson, Abner W., University of Minnesota
12362 Anderson, Edward S., University of Minnesota
12363 Ellestead, Irwin M., University of Minnesota
12364 Palmer, Roy A., University of Minnesota
12365 Sannicoto, Joseph F., University of Minnesota
12366 Bjonerud, Earl S., University of Minnesota
12367 Hagelin, Lawrence W., University of Minnesota
12368 King, John E., University of Minnesota
12369 Bosshardt, Willmert, C., University of Minnesota
12370 Pangburn, Carroll G., University of Minnesota
12371 Plank, Howard G., University of Minnesota
12372 Morton, Lysle W., University of Minnesota
12373 Carlson, Richard E., University of Minnesota
12374 Dunnavan, Ralph B., University of Minnesota
12375 Wills, David C., University of Minnesota
12376 Lilley, John M., University of Minnesota
12377 Wilson, Frank W., University of Minnesota
12378 Schweiso, Clifford C., University of Minnesota
12379 Dahl, Harold W., University of Minnesota
12380 Tomeraasen, Theron L., University of Minnesota
12381 Teal, Clarence W., University of Minnesota
12382 Slabodnik, Mark, University of Minnesota
12383 Peterson, Martin, University of Minnesota
12384 Johnson, James P., University of Minnesota
12385 Fischer, Harold W., University of Minnesota
12386 Steffens, Robert A., University of Minnesota
12387 Taplin, George, University of Minnesota
12388 Babcock, Vernon M., University of Minnesota
12389 Appleman, Frank C., University of Minnesota
12390 Hecht, Henry W., University of Minnesota
12391 Hatchett, Ralph T., School of Engineering of Milwaukee
12392 Camp, Norman G., Alabama Polytechnic Institute
12393 Hayley, Arthur L., Alabama Polytechnic Institute
12394 Scarborough, Charles L., Jr., Alabama Polytechnic Institute
12395 McDavid, David L., Alabama Polytechnic Institute
12396 Roberson, James D., Alabama Polytechnic Institute
12397 Breedlove, Frederick W., Alabama Polytechnic Institute
12398 Bailey, Julian C., Alabama Polytechnic Institute
12399 Osborn, Fred W., Alabama Polytechnic Institute
12400 Jenkins, Fred W., Alabama Polytechnic Institute
12401 Prosser, Samuel M. S., Toronto Central Technical School
12402 Bell, Adam, Toronto Central Technical School
12403 Dumelow, John C., Armour Institute of Technology
12404 Poole, Robert E., Stevens Institute of Technology
12405 Millard, Fred P., Worcester Polytechnic Institute
12406 Gray, Robert, Toronto Central Technical School
12407 Powell, Baden, Toronto Central Technical School
12408 McConnell, Harvey O., Toronto Central Technical School
12409 Smiley, David W., Toronto Central Technical School
12410 Hyatt, George H., Toronto Central Technical School
12411 D' Autremont, Roy F., Iowa State College
12412 Smith, Roland C., Iowa State College
12413 Kibble, Arthur L., Iowa State College
12414 Funck, Elmer H., Iowa State College
12415 Peter, Emil H., Iowa State College
12416 Bryan, Lowell V., Iowa State College
12417 Barrans, William T., Iowa State College
12418 Hudson, Glenn B., Iowa State College
12419 Bennison, Russell D., Iowa State College
12420 Turner, Robert E., Iowa State College
12421 Nickelsen, E. A., Iowa State College
12422 Schneider, Harold B., Iowa State College
12423 Rieke, Clyde R., Iowa State College
12424 Barnheld, Leslie P., Iowa State College
12425 Swanson, Dale H., Iowa State College
12426 Rathbun, Lloyd M., Iowa State College
12427 Vannoy, John L. C., Iowa State College
12428 Plumb, Carroll E., Iowa State College
12429 Braun, Elmer H., Iowa State College
12430 Ross, Russell O., Iowa State College
12431 Schulze, Harley C., Iowa State College
12432 Eliason, Oscar C., Iowa State College

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Measurement of Relative Eddy Current Losses in Stranded Cables

BY JAMES A. COOK
The New York Edison Company.

THE amount of energy dissipated by eddy currents in copper conductors is a matter of interest in many branches of the electrical industry. Eddy current losses in stranded copper cables constitute a source of heat. If the alternating flux density is high at usual operating frequencies, the eddy current losses may seriously restrict the conductor rating based on permissible temperature rise. This paper has been prepared, therefore, to describe a method which will provide accurate measurements of eddy current losses on a comparative basis. The method of test is not advanced as being original with the author, but represents the accumulated experience of the Test Department of The New York Edison Company with several series of tests of this character.

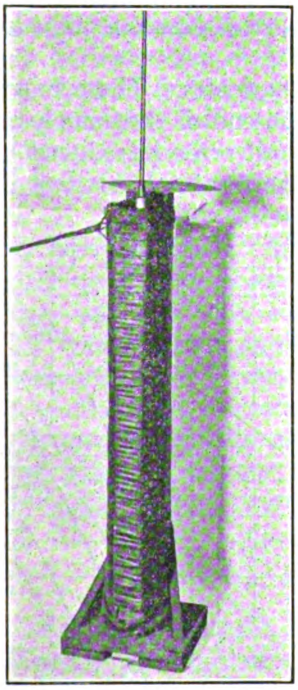


FIG. 1—FIELD WINDING FOR MEASURING RELATIVE EDDY CURRENT LOSSES IN STRANDED CABLE

To be presented at the 9th Midwinter Convention of the A. I. E. E., Feb. 16-18, 1921.

Investigations have been made at various times to determine the effectiveness of various expedients for reducing such losses. These include, for example, (1) impregnating bare cables with varnishes and compounds to insulate the strands from each other, and (2) insulating layers of strands from each other by wrapping the layers with asbestos tape during manufacture of the cable. The relative eddy current loss was determined for the bare and insulated condition; other factors held constant.

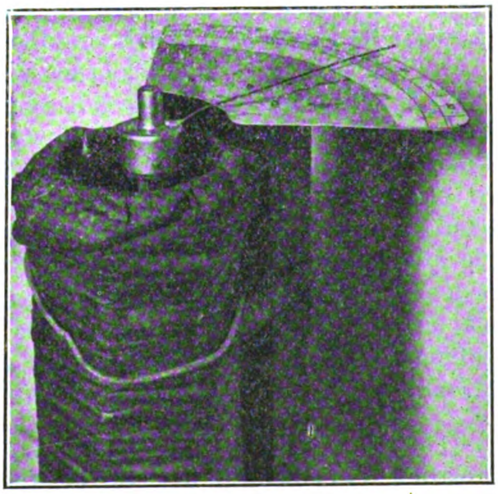


FIG. 2—SUSPENSION OF CABLE SAMPLE IN FIELD, SHOWING BIFILAR SUSPENSION AND SCALE FOR MEASURING DEFLECTIONS

Fig. 1 shows an air-core coil wound with three phases to produce a rotating field. The coils are on a five-inch fiber tube 36 inches long. The winding is full pitch, two-pole, each phase consisting of 100 turns of No. 22 A. W. G. insulated copper wire.

A two-foot length of cable to be tested is hung in the center of the coil by a bifilar suspension as shown in Figs. 2 and 3. Care is taken in cutting the sample not to disturb the lay of the strands. A pointer was mounted as shown in the illustrations to indicate the angular deflection of the cable from the free position.

Balanced field currents were then applied. The

rotating field so produced set up eddy currents in the stranded cable sample, resulting in torque and rotation of the sample until balanced by the torque of the suspension. The angle of deflection is a measure of the torque which can be determined from the dimensions of the suspension as follows:

l = length of suspension threads in cm.
d = distance between centers of suspension threads in cm.
m = mass of sample and suspension cap in gm.
g = acceleration due to gravity = 980 cm-sec.[2]
θ = angle of deflection in degrees.
t = torque due to eddy currents.

$$t = \frac{m\,g\,d^2}{4\,l} \sin\theta \text{ dyne-cm. approximately} \quad (1)$$

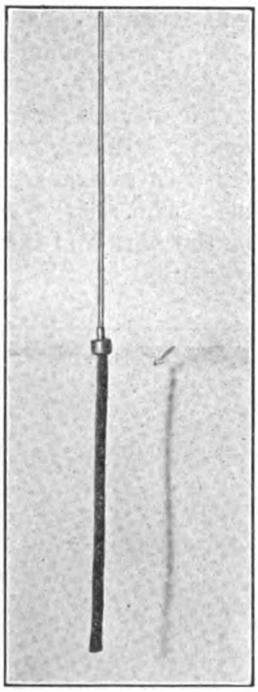


Fig. 3—Method of Attaching Cable Sample to Bifilar Suspension

This relation is substantially correct for small deflections. If $l = 100$ cm., $d = 2$ cm. and $\theta = 30$ degrees, the error introduced by using the approximate formula is less than 1 per cent. In the actual tests described below, the error from using this approximate formula is less than in this assumed case.

With the torque determined, the watt loss by eddy currents p may be computed from the known speed of the rotating field.

$$p = 2\,\pi\,f\,t\,(10)^{-7} \text{ watts.} \quad (2)$$

This use of a bifilar suspension assumes that there is no torsional moment in the suspension and for this reason silk threads are preferable to wire in constructing the suspension.

All cable samples were bound at each end and in the center before being cut from the piece. This was done to keep the strands as nearly as possible in their normal condition. The lashings were not disturbed during the test.

At the ends of the sample where cut, there was a slight burring of the strand ends which had an appreci-

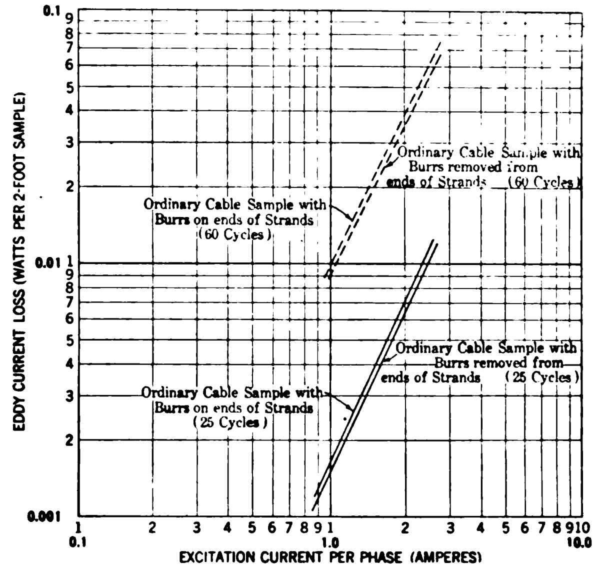


Fig. 4—Eddy Current Losses in Copper Cables
650,000-circular mil—37-strand cable

able effect on the losses. These burrs were removed by immersing the end of the sample in sulphuric acid and the amount of error introduced by the burr was determined. The result of this test is shown in Fig.

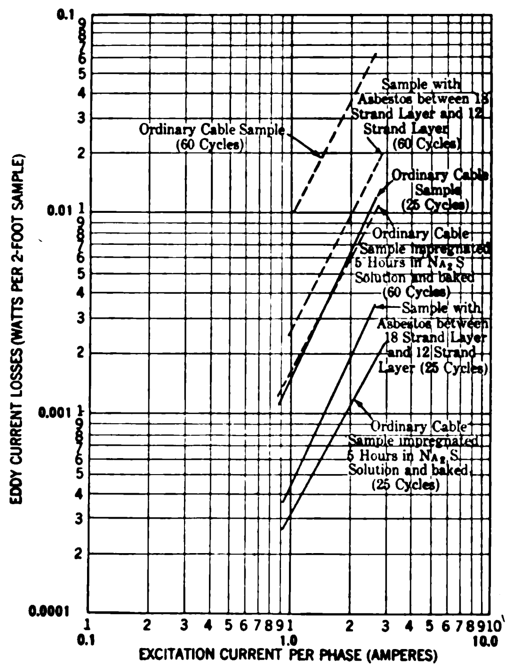


Fig. 5—Eddy Current Losses in Copper Cables
650,000-circular mil—37-strand cable

4. It will be seen that the end effect is comparatively small.

Fig. 5 shows the relative eddy current losses in three samples of 650,000-circular mil, 37-strand cable.

TABLE I—EDDY CURRENT LOSSES IN WATTS FOR TWO-FOOT CABLE SAMPLE.
650,000-Circular Mil Cable 37 Strands
Excitation Current 2 Amperes In Each Test

	As cut from reel		After treating ends with H_2SO_4 to remove burrs		After immersion 5 hours in Na_2S solution and baking one hour at 105 deg. cent.		After bending samples treated with Na_2S solution to arc of circle and straightening			
	25 Cycles	60 Cycles	25Cycles	60 Cycles	25 Cycles	60 Cycles	Radius	No. of times bent	25 Cycles	60 Cycles
Ordinary cable sample........	0.0074	0.041	0.0066	0.037	0.0013	0.0061	14 inches	10	0.0011	0.0061
Cable with asbestos tape between 18-strand layer and 12-strand layer............			0.0020	0.010						

The samples were tested at 25 cycles and at 60 cycles after preparation as follows:

1. Sample cut from cable (no asbestos) and burrs removed from ends with sulphuric acid.
2. Same as in (1) except that the sample was also immersed for five hours in a sodium sulphide solution and then baked one hour at 105 deg. cent.
3. Same as in (1) except that sample was cut from a cable having asbestos tape separating the 18-strand layer from the 12-strand layer.

Reference to Fig. 5 shows the eddy current losses are very considerably decreased from normal by use of asbestos tape between the eighteen-strand layer and the twelve-strand layer. A greater reduction is effected by taking the bare cable and impregnating it with sulphide solution followed by baking. The effect of this impregnation is to form an insulating film of copper sulphide on the individual strands, thus reducing the eddy current losses. An examination of the samples after treatment showed thorough impregnation of the cable by the solution. The individual strands had copper sulphide coating of uniform thickness and at only very few points was the bare copper visible, thus indicating that adjacent strands had been in exceptionally close contact. To determine if the sulphide coating would withstand bending of the cable, strands were bent until the sulphide coating cracked off. It was necessary to bend to a radius of one or two inches before this resulted. The sulphide solution selected consisted of a 10 per cent solution by weight of sodium sulphide. To every 100 parts of this solution, 5 parts by volume of sulphuric acid (specific gravity 1.20) were added.

Samples of cable were bent to arcs of circles of 14-in. and 18-in. radii respectively, and were then straightened and eddy current loss again measured. One sample was bent to a radius of 14 in. ten times in succession. In this instance the losses were smaller than after one bending. This was probably due to the fact that the strands in the cable started to bulge and consequently were in less intimate contact. Table I gives the comparative results of the series of tests made under the conditions described above with excitation of two amperes per phase in all tests.

Sources of error to be avoided are:

1. Burring of cable strands in cutting sample.
2. Failure to suspend the samples in center of field.
3. Disturbance of strands of sample from their normal position, by bending or careless handling.

With suitable precautions, the results of the tests with apparatus described herein are correct within 5 per cent and serve to demonstrate the effectiveness of the various methods of treating stranded cable to reduce eddy current losses.

SAVING PREVENTS ACCIDENTS IN INDUSTRY

Saving and the practise of thrift have always been advocated as a means of obtaining a nest-egg for the future. It has recently been suggested that saving is one of the best preventives of accidents.

This was the opinion of safety engineers and experts at the Industrial Safety Congress, held in Syracuse recently. Many experts held the view that when a man is not worried about financial or other matters, he can concentrate more fully on his job.

Safety engineers and experts in industrial problems present at the Safety Congress were of the belief that a large percentage of industrial accidents could be charged directly to carelessness, superinduced by domestic troubles as generally of a financial nature. They stated that where workers save their money and are financially secure, they are more attentive to their work, more careful about what they do and therefore help greatly in preventing industrial accidents.

The United States Treasury Savings movement aims at encouraging the spirit of saving and in issuing its securities in popular denominations, places them within easy reach of everyone in this country and thus promotes financial security. An individual savings fund means better housing conditions for workmen, insuring better health, steadier nerves, better food, better clothing and a reserve for timely medical attention. It enables them to get ahead, which means greater hopefulness reflected in greater production.

Employers have stated that by forming Government Savings Associations in industrial establishments the Treasury Department is performing an invaluable service which, strangely enough, has the result indirectly of helping decrease the number of accidents to workmen.

Permissible Operating Temperatures of Impregnated Paper Insulation in which Dielectric Stress is Low

BY PHILIP TORCHIO

Chief Electrical Engineer, New York Edison Co.

The writer reviews the effect of temperature on insulating materials, abstracting from the 1913 *Steinmetz and Lamme report, and the 1905 British Engineering Standards Committee tests. Then he gives surveys of low-tension cables in large distributing systems, and special tests on cables including sheath cracking, high temperature tests, effect of bending on cables heated at high temperatures, distillation of cable compounds, ambient temperatures in subway ducts as affected by thermal conductivity of concrete, amount of moisture in soil, different arrangements of ducts and load factors at which the cables are operated.*

From this review, conclusions are derived that the permissible operating temperatures are to be a function of the load factors at which the cables operate. The writer recommends 105 *deg. cent.,* 95 *deg. cent. and* 90 *deg. cent. for load factors of* 33 *per cent,* 50 *per cent, and over* 66 *per cent, respectively.*

A LARGE amount of study has been given in the last seven years to the limiting temperatures of high-tension cables and the attendant dielectric losses. (For details, refer to A. I. E. E. TRANS., Vol. XXXVI—1917, p. 417-527). As these losses begin to increase sharply for voltages higher than 5000 volts around 70 deg. cent., for paper impregnated with vegetable compounds, and 80 deg. cent. for paper impregnated with mineral compounds, an arbitrary limit of "85 deg. cent. minus E in thousand volts" was adopted in the Standardization Rules. With the preponderant feature of dielectric losses in mind, very little consideration was given to low-tension cables per se, so that the arbitrary constant in "85 deg. cent. minus E" became 85 deg. cent. for low-tension cables. It is the object of this paper to deal more intimately with low-tension cables and to present results of extensive investigations and special tests, together with a review of the results of long years of practise.

1. EFFECT OF TEMPERATURE ON INSULATING MATERIALS

In approaching the subject, it may be opportune to quote from the paper of Steinmetz and Lamme of 1913:

> Paper insulation will have a comparatively long life even at ultimate temperatures as high as 100 deg. cent. * * *. At materially higher temperatures than 100 deg. cent. the life is greatly shortened, and temperatures of 125 deg. cent. will apparently ruin the insulation, from the mechanical standpoint, in possibly a few weeks, *if such temperature is maintained steadily.* However, for low voltages, insulating qualities may still be very satisfactory even at this temperature (125 deg. cent.) * * *.

The 1913 paper of Steinmetz and Lamme had been written to present general information on behavior of different insulating materials used in construction of electrical apparatus and to furnish a basis for work of the A. I. E. E. Standards Committee, which culminated in the promulgation of the Standardization Rules in 1916. It is of assistance to us in discussing the problem to refer to these rules for the class of materials under which impregnated paper is classed, *i. e.*, Class A insulation. The limiting temperature allowed by the Rules for Class A insulation is 105 deg. cent. *continuous*.

2. BRITISH STANDARDS ENGINEERING COMMITTEE

It may be of interest here to reproduce results of careful tests made in 1905 by the Engineering Standards Committee of Great Britain. These tests, at the time the A. I. E. E. Rules were worked out, were probably the most comprehensive study then published. I am selecting from numerous tests on a great number of materials some that more closely approximate the condition of impregnated paper.

The tests were made by subjecting the samples either to continuous temperatures or temperature over periods of twelve hours daily for several months up to nine months or one year. The samples were tested for dielectric strength, shearing and bending. The shearing test was determined by the use of a punch of one-half inch in circumference, and determining the pounds pressure at which the samples broke. The bending tests consisted in taking a strip of the insulation sample and bending it over a series of cylinders of gradually decreasing diameters, note being taken of the cylinder diameter over which the fracture would first occur.

A number of curves showing the results of the shearing and bending tests of various samples of insulation are presented. In either case, the *total number of hours, with the heat on,* was computed, omitting the hours when the heat was off, so that the abscissas represent the *equivalent weeks of continuous heating.*

For the object of comparison, instead of giving the pounds test pressures for each sample, the shearing tests are plotted in per cent of the shearing strength of the unheated sample, taken as 100 per cent. The shearing curves in Figs. 1 and 2 have been interpolated from results of two separate investigations on similar samples of Manila paper, extending approximately 9 and 30 weeks, while the shearing curves in Figs. 3 to 6 were obtained from tests taken at 12 periods throughout an interval equivalent to 26 weeks' continuous heating.

To be presented at the 9th Midwinter Convention of the A. I. E. E., Feb. 16-18, 1921.

The bending curves in Figs. 7 to 14 are interpolated from the results of three separate investigations on similar samples extending 4, 9, and 30 weeks, respectively. The ordinates of these curves represent the minimum diameter of cylinders over which the samples can be bent without fracture, and they are interpolated for 75, 100, and 125 degrees heating.

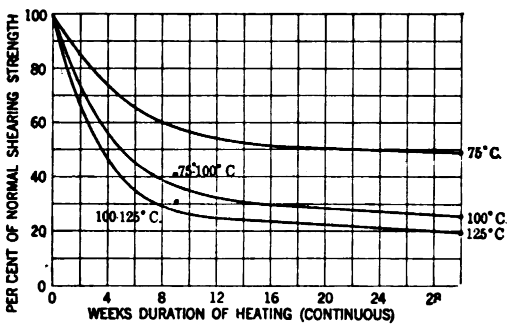


Fig. 1—Manila Paper—0.012 in. (0.3 mm.)

The *bending curves* for various materials *cannot be compared directly* as the bending test is a function of the insulation thickness which varies in each case.

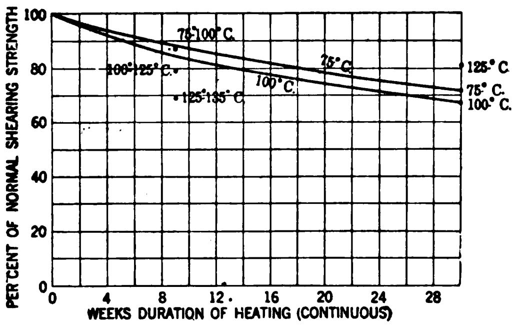


Fig. 2—Manila Paper Varnished—0.014 in. (0.355 mm.)

However, they are of interest to show the bending qualities of each sample as compared to its original unheated condition. In many cases, a $\frac{1}{16}$-inch cylinder

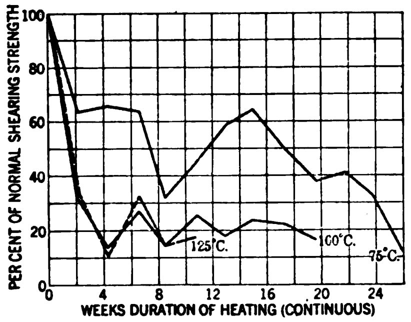


Fig. 3—Empire Cloth—0.040 in. (1.016 mm.)

is shown as a minimum and most samples could be bent in the unheated state ten or more times over this cylinder without injury. For the large diameters, however, the curves represent a single bending.

Fig. 1 gives the shearing tests on a sample of untreated Manila paper of 12-mil thickness. The shearing strength of the heated samples has been greatly reduced at the end of the 30th week over the unheated sample; the percentages being 49, 25, and 19 for the

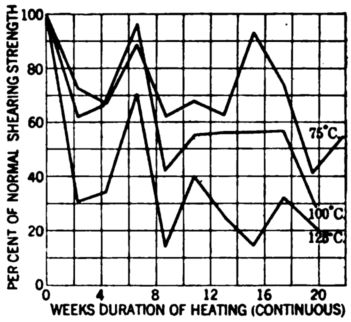


Fig. 4—Calico Impregnated with Elastic Insulating Varnish—0.016 in. (0.406 mm.)

75, 100, and 125-deg. cent. heating, respectively. Corresponding to the shearing curves in Fig. 1 are shown the bending curves of Manila paper in Fig. 7. The

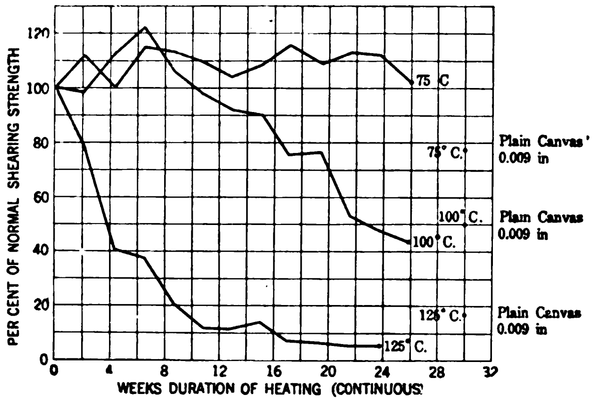


Fig. 5—I. R. Prepared Duck—0.027 in. (0.686 mm.)

unheated sample could be bent over a $\frac{1}{16}$-inch cylinder ten or more times without injury. After being heated for 30 weeks, the sample could only be bent around

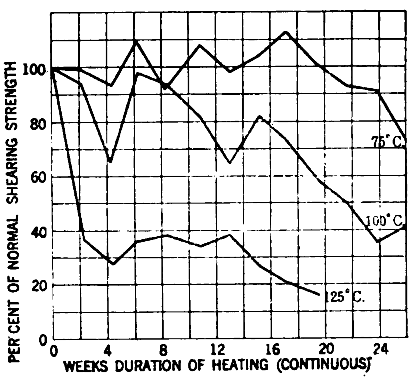


Fig. 6—Press-Spahn—0.040 in. (1.016 mm.)

cylinders of ¼-, 1½- and 2-inch diameters for the 75, 100, and 125-deg. heating, respectively.

Fig. 2 gives the shearing tests of a sample of varnished Manila paper of 14-mil thickness. (Only the 75 and

100-deg. cent. curves have been drawn as the 125-deg. points seemed somewhat irregular. The values are, however, the average of several tests taken on different part of each specimen.) After being heated for 30 weeks at 75, 100, and 125 deg. cent., these varnished Manila paper samples had values of shearing strength

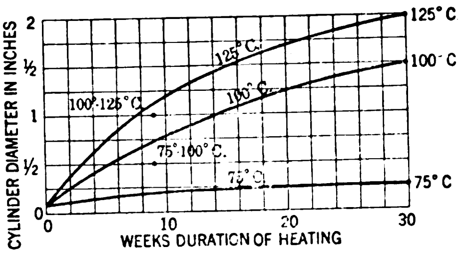


Fig. 7—Plain Manila Paper—0.011 in. (0.23 mm.)

equal to 71, 68, and 81 per cent respectively, of the unheated sample. Their shearing strength is, therefore, retained to a much greater extent than in the untreated Manila paper samples.

Corresponding to the shearing curves for varnished Manila paper shown in Fig. 2 are the bending curves shown in Fig. 8. The unheated sample could be bent

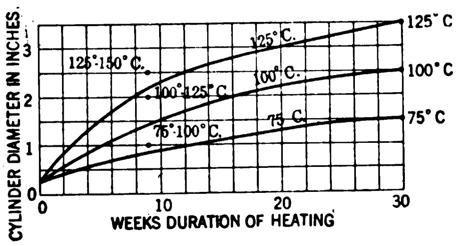


Fig. 8—Manila Paper, Varnished—0.014 in. (0.355 mm.)

around a ¼-inch cylinder without injury, while the samples heated at 75, 100, and 125 deg. cent for 30 weeks could only be bent around cylinders of 1½-, 2½- and 3½-inch diameters, respectively.

Only rough bending tests were taken on samples whose shearing curves are shown in Figs. 3 to 6.

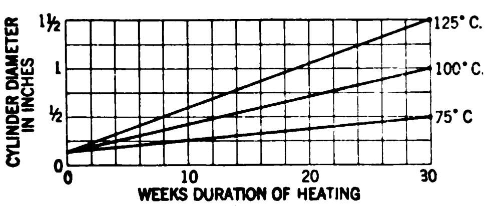


Fig. 9—Canvas Varnished—0.0157 in. (0.40 mm.)

They were bent to and fro, and note taken as to whether they cracked or broke.

Fig. 3 gives the shearing tests for empire cloth. The sample was destroyed at the end of the 20th week at 100 deg. cent., while the sample heated at 125 deg. cent. was destroyed at the end of the 11th week.

Fig. 4 gives the shearing tests for a sample of calico impregnated with elastic insulating varnish. The 75-degree sample broke on bending at the 20th week; the 100-degree sample at the 4th week; and the 125-degree sample at the 2nd week.

Fig. 5 gives the shearing tests for a sample of I. R. prepared duck (reinforced rubber). The 75-degree sample was practically unaltered at the end of the

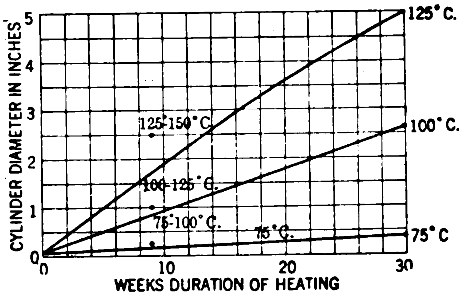


Fig. 10—Berrite Fabric—0.013 in. (0.33 mm.)

26th week. The 100-degree sample showed only 43 per cent of its shearing strength for the same time, while the 125-degree sample broke on bending at the end of the 24th week. (On the same figure are shown the shearing values of untreated canvas of 9-mil thickness, heated at 75, 100, and 125 deg. cent. for 30 weeks).

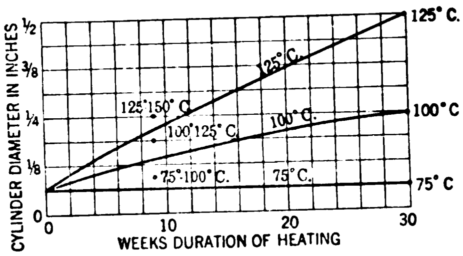


Fig. 11—Excelsior Linen—0.0063 in. (0.16 mm.)

Fig. 6 gives the shearing tests for a sample of press-spahn. The 75-degree sample cracked on bending at the 26th week, but was practically unaltered up to the 22nd week. The 100-degree sample cracked on bending at the 20th week, while the 125-degree sample broke on bending at the end of the 2nd week.

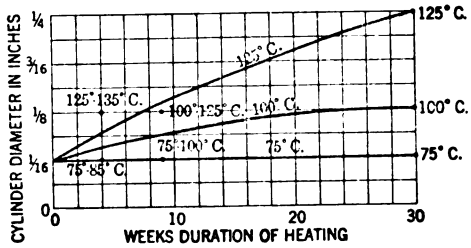


Fig. 12—Excelsior Paper—0.0047 in. (0.12 mm.)

Bending tests of other samples of insulation, such as varnished canvas, Berrite fabric, press-spahn, and oiled cloth, are shown in Figs. 9 to 14 inclusive.

In general, treated Manila paper compares very favorably in shearing strength with other types of vegetable fibrous insulation, and it also has the same

general bending characteristics. Varnished Manila paper of 14-mil thickness, at the end of 30 weeks' heating at 100 deg. cent., still had a shearing strength of 68 per cent of the unheated sample, and could be bent around a cylinder of 2½-inch diameter, while the same temperature destroyed a sample of empire cloth at the 14th week, of I. R. prepared calico and press-spahn at the end of the 16th week, and of varnished calico at the end of the 18th week.

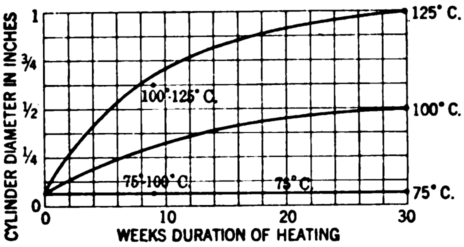


FIG. 13—PRESS-SPAHN—0.010 IN. (0.25 MM.)

In practically all samples, *the dielectric strength showed but small deterioration until mechanically destroyed.*

3. APPLICATION TO CABLES

Having before us these results of different insulating materials, we may review their limitation to specific uses by applying our engineering judgment. It is, of course, difficult to make an exact comparison of the conditions under which insulating materials are to operate in the great variety of apparatus to which they are applied.

However, we may start from the point that impregnated paper, under the A. I. E. E. Standardization Rules as Class A insulation, is good for 105 deg. cent. continuous. It is not here the case of discussing whether this limit is too high or not. Personally,

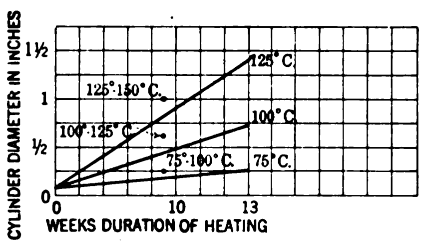


FIG. 14—OILED CLOTH—0.0087 IN. (0.22 MM.)

after studying similar data as given in the British Committee tests, from which I have abstracted the few illustrations in the foregoing paragraphs, I feel that 105 deg. cent. is too high if applied continuously; but to this I shall make reference later. For the present, we may assume that impregnated paper as Class A insulation should withstand safely 105 deg. cent. If such is the case, what consideration would prevail to modify this limit on account of the possible different conditions that might exist in cables versus other electrical apparatus like armature coils, et cetera?

3A. REASONS ADVANCED FOR LOW TEMPERATURE LIMITS

The principal reasons advanced for adopting lower temperature limits than 105 degrees cent. for cables have been two:

1. That the compound in the cable, when warm, may leave the paper, especially when the cable is installed in inclined ducts, with a tendency to flood the lower portion of the cable and to leave the upper part of the cable dry.

2. That cables are oftentimes removed from subways for reinstallation in other locations and, therefore, if the paper becomes brittle, it would crack inside the lead sheath.

Another reason for advocating the lower temperatures is that the expansion and contraction of long lengths of *large size lead-covered cables* may cause cracking of the lead sheath at sharp bends in manholes.

3B. THE RELATION OF TEMPERATURE LIMIT TO LOAD FACTOR

It is now my purpose to present data to prove that these reasons are insufficient to make an exception to the Standards Rules for Class A insulation for 105 deg. cent. for low-tension cables; but before presenting these facts, I want to emphasize the point that while in machinery the 105-degree allowable limit is reached for long periods of time of operation of the apparatus, on the other hand, *low-tension cables, as usually used in large distributing systems, are not subjected to the maximum temperature except for short periods of time each day,* so that in such cases the 105 *deg. cent. for the low-tension cables is immeasurably safer* than the 105 *deg. cent. for machinery,* which may operate at that temperature continuously or at least for periods of eight or ten hours each day. Anticipating my conclusion, I will broadly state that the *limiting temperature* should be a *function of the load factor* (*average load to yearly maximum*) under which the apparatus is to operate, so that *if the apparatus, either cable or machinery, is to operate for long hours at full load, the limiting temperature should not exceed say* 90 *deg. cent.,* while on the other hand, *if the cable or machinery is to operate for a short number of hours* at heavy load and then be subjected to a long period of cooling, as occurs on cables in large systems of distribution, the limiting temperature for the peak loads should be raised, and the 105 deg. cent. limit should be standardized.

4. SURVEYS AND TESTS

I herewith submit conclusive evidence of the fact that 100 deg. cent. to 110 deg. cent. are safe and standard in practise in large subway and distributing systems. The evidence consists of (1) results from observations obtained by wide and close scrutiny of the physical and electrical conditions of all the low-tension cables of a large electric power company, The New York

Edison Company; and (2) results of special tests carried out by engineers and laboratory men.

4A. Field Surveys

Investigations of a very thorough and exhaustive character were prompted by three occurrences, unprecedented in the history of the company, of serious short circuits of low-tension cable feeders. These occurrences were at first unexplainable and therefore were highly perplexing to the managers and engineers. The coincidence of these disturbances at the period of the winter of 1919 when the company was called upon to furnish an unprecedentedly and unexpectedly heavy increase in power demand, causing the low-tension cables to carry heavier loads than customary in any previous year, naturally led one to suspect that the cable insulation might have been damaged.

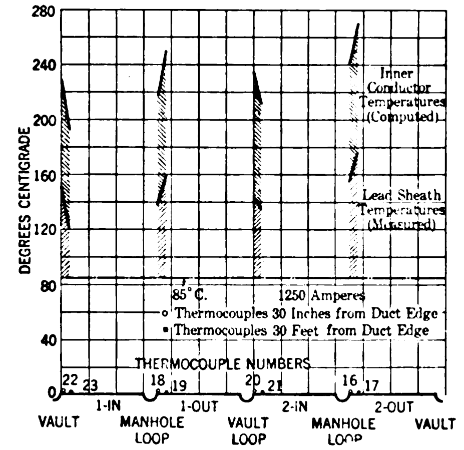


Fig. 15—Maximum Temperatures—Cable Sheath Cracking Test

The results of the physical inspection of all cables showed that a number of 1,000,000-cir. mil concentric feeder cables, not necessarily carrying heaviest loads, but in congested banks of ducts, had their sheaths cracked near the edge of the ducts and at sharp bends in manholes where the movement of the cables, due to expansion and contraction, was impeded. These cracks extended to the insulation, leaving an open path for moisture and water to reach the copper and to cause a local short circuit, which would endanger the neighboring cables and cause manhole explosions. It is not here the place to enter into a description of ways and means developed to securely protect the system from these dangers of low-tension cable short circuits, but what is of vital interest is the fact that *not a foot of cable was found with impaired insulation* outside the point of the crack or burn-out at the short circuit. That is, that cable a few feet from the burn-out, and all the rest of its length, was thoroughly sound and undamaged.

4B. Sheath Cracking and High-Temperature Tests

One of the numerous special tests carried out in the comprehensive study of the subject throws additional light on the findings of the physical inspection of all the cables on the system. We made a series of tests on four 278-ft. lengths of cables installed in ducts between manholes connected in series, with bends and splices to simulate actual conditions. The object was to determine loads, temperatures, and expansion of cables at which the sheaths would crack if the cables were submitted to specified cycles of eight-hour load and sixteen-hour no-load for periods of weeks, extending over two months. Temperatures of sheaths were taken by thermocouples and the inner copper temperatures calculated, using the Atkinson constant of thermal resistivity of 354, which we have independently checked and which seems to be approximately correct. Fig. 15 gives the maximum temperatures for lead sheath and inner copper for the different thermocouple locations at a 1250-ampere run. Figs. 16, 17 and 18 give characteristic runs at 800, 1000, and 1250 amperes continuous load for eight hours. Inner copper temperatures at location of thermocouple No. 20 for the full period of test are graphically represented in Fig. 19. From the diagram, it appears that the insulation at the point "thermocouple No. 20" withstood the following temperatures:

Inner Conductor Temperature (Degrees C.)	Hours	Remarks
Less than 85	73	Hours of tests with current on —exclusive of hours of cooling with current off.
85—90	13	
90—100	26	
100—110	37	
110—125	88	
125—150	36	
Over 150	169	
Total duration of test periods	442	

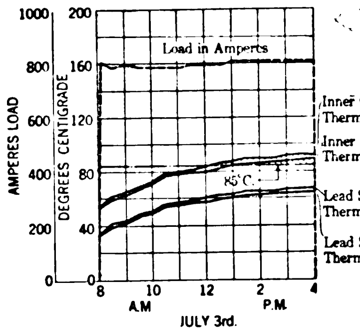


Fig. 16—Cable Sheath Cracking Test
800-Ampere d-c. run

The sample of cable at location "thermocouple No. 20" showed its insulation in good condition, the inner insulation being darkened and of considerably reduced tensile strength, but yet in perfect condition

for indefinite service, notwithstanding the fact that the insulation operated at over 110 deg. cent. for 293 hours; temperature of over 125 deg. for 205 hours; and temperature of over 150 deg. for 169 hours.

At other locations, the maximum temperature exceeded the temperature noted for location "thermocouple No. 20." (See Figs. 15 and 18). At thermo-

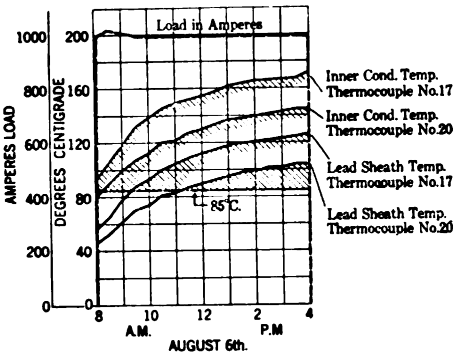


Fig. 17—Cable Sheath Cracking Test
1000-Ampere d-c. run

couple No. 17, the copper temperature reached a maximum of 269 deg. cent., and temperature in excess of 240 deg. cent. existed for 4½ hours.

4c. Effect of Bending

With these enormously high temperatures, only 20 feet of one length, out of the 1112 feet of cable, had their insulation destroyed. The four lengths were

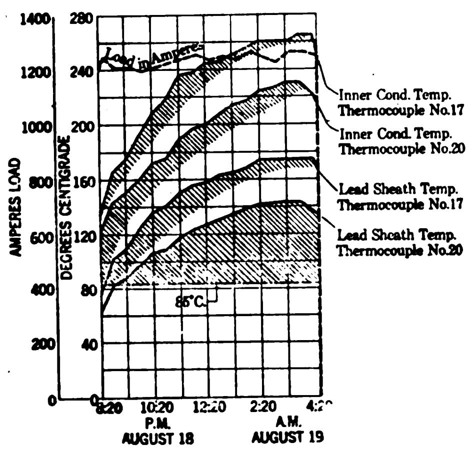


Fig. 18—Cable Sheath Cracking Test
1250-Ampere d-c. run

removed from the ducts and reeled, and re-reeled in some instances twice, and after this handling the cable lengths were subjected to regular factory voltage and insulation tests, with the following results:

		Voltage Tests 5-minute application		Insulation Test megohms per mile	
Section	No. of times re-reeled	Inner to outer and lead	Outer to inner and lead	Inner to outer and lead	Outer to inner and lead
1 in	1	5400	5900	460	184
1 out	2	5400	*	770	...
		5500	5700	703	289
2 in	1	5500	6600	100	56
2 out	2	5400	5800	520	105

*Broke down 12 feet from the end near hub of reel after two minutes at 6000 volts. Balance portion retested with results in second line "1 out."

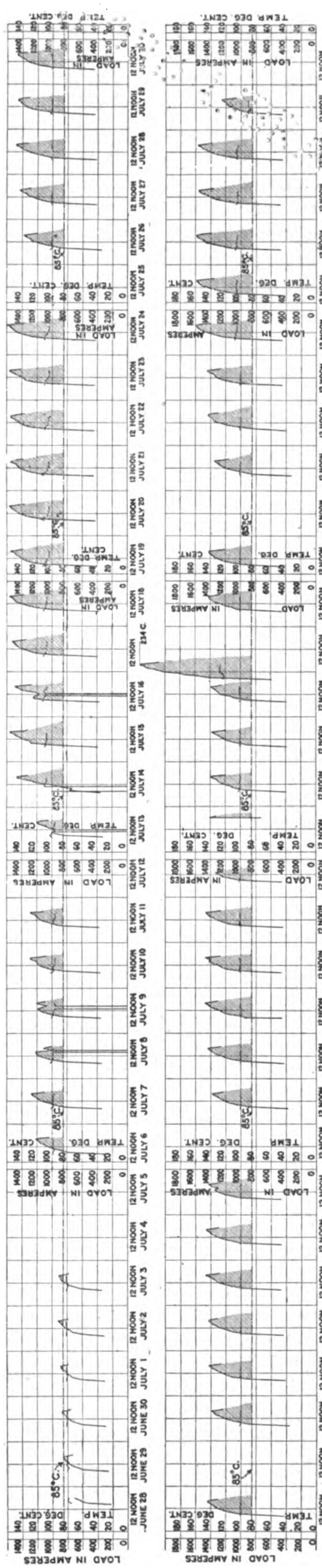


Fig. 19—Inner Copper Temperatures at Location of Thermocouple No. 20 for Period of Test

Apparently even after the withdrawing and rehandling of this cable, which had been subjected to such high temperatures, in excess of 200 deg. cent., over 98 per cent of the cable was still in such fair condition that it would have been reinstalled, if the lot had come from ordinary withdrawals. The insulation of this cable that, at thermocouple No. 20, withstood for 169 hours temperatures of over 150 deg. cent., must have been immeasurably more affected than if the temperature had been limited to 105 deg. cent. for a great number of years of service during the winter

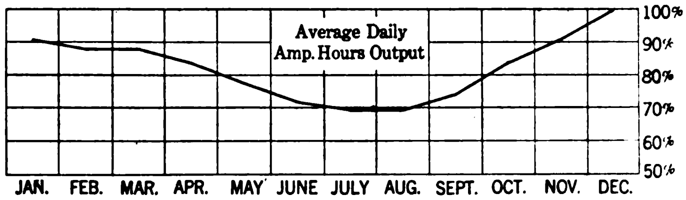


FIG. 20

peaks as prevailing on large systems of distribution· (Time does not permit of figuring out the total hours of high, average, and minimum temperatures engendered by the characteristic load curves for different seasons of the year; but for any one interested in the subject, I attach diagrams of average daily output throughout the year, and characteristic load diagrams for each season of the year, as per Figs. 20 and 21). The point that may be made here is that the operation of a cable at 105 deg. cent., in ordinary systems of distribution, will not prevent the cable from being removed and reinstalled without injury.

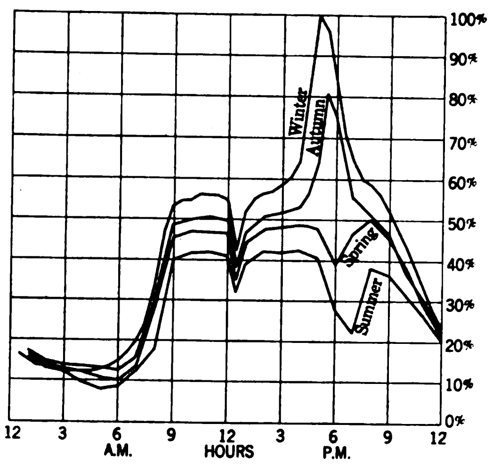


FIG. 21

4D. OTHER COMPANIES' EXPERIENCE

The experience of several large companies, like The New York Edison and Commonwealth Edison Company of Chicago, who have operated for the last twenty years a substantial number of their cables at loads producing temperatures of 100 to 110 deg. cent. during the winter peaks, proves without question that these seasonal temperatures for periods of peak loads have not impaired the cable or its insulation for occasional withdrawal and reinstallation any more than on cables of the same age which have never sustained but lower temperature. The hardening of the oil in the insulation which, as we have seen, takes place if temperatures of 100 deg. cent. and over are sustained continuously for periods of several months, will either not take place at temperatures of 105 deg. cent. applied only for short periods for certain seasons of the year; or if any hardening takes place, the process will extend over long periods, exceeding 15 or 20 years. At the ends of these periods, it is improbable that any substantial amount of such cable will still be required for reinstallation, if removed, but if the lead sheath is intact, the tests on the sample cables submitted to almost destructive temperatures have shown that the cable can still be reeled and re-reeled without destroying its efficiency for service both as to dielectric strength or insulation resistance; in practise, the aging and deterioration of the lead sheath, due to chemical action electrolysis, et cetera, will be the *paramount factor in the life of low-tension cables.*

Regarding the question of the compound leaving the insulation, I think it can be dismissed by considering the fact that this migration of compound will only be partial, and whatever remains of the compound with the paper still offers a factor of safety in dielectric strength from ten to twenty-five times the low-tension operating voltage.

The difficulties of lead sheaths cracking in large sized cables are essentially problems of careful installation and handling of the cable. In the sheath cracking test, we have been unable to produce cracking under the extraordinarily severe conditions of temperatures which gave expansions as large as 8 inches in 278 feet. In practise, with 105 deg. cent. temperatures, the expansion would only be 3¼ inches.

5. DISTILLATION TEMPERATURES OF CABLE COMPOUNDS

The question has also been raised that the compound might distil or vaporize at temperatures of above 100 deg. cent. An exhaustive investigation was made by The New York Edison Company to determine the effect of temperature on cable impregnating materials. The results of laboratory tests carried out by the Electrical Testing Laboratories indicated that the mineral compound gave the first drop of distillate at 205 deg. cent. A supplementary investigation was made to determine if the compounds would distil any appreciable amount at temperatures below 200 deg. cent. when exposed to these temperatures for long periods of time. No distillate, however, was obtained for either mineral or resin compounds after being maintained successively at temperatures of 115, 130, 145 and 160 deg. cent. for three days. Similar results were obtained when the temperature was maintained at 180 and 200 deg. cent. for 24 and 36 hours.

To further determine if the increasing temperature produced any gas within the cable, an investigation

was made with a test tube and the temperature raised from 100 to 200 deg. cent., an attempt being made to ignite the vapor above the surface of the compound at the different temperatures. In the case of the mineral compound there was absolutely no tendency to ignite throughout these temperatures. With the resin compound, however, it was found that the passage of a spark at a temperature of 145 deg. cent. caused the vapor to explode, this action continuing up to 160 deg. cent. behind which no further explosions took place as the temperature was raised to 200 deg. cent.

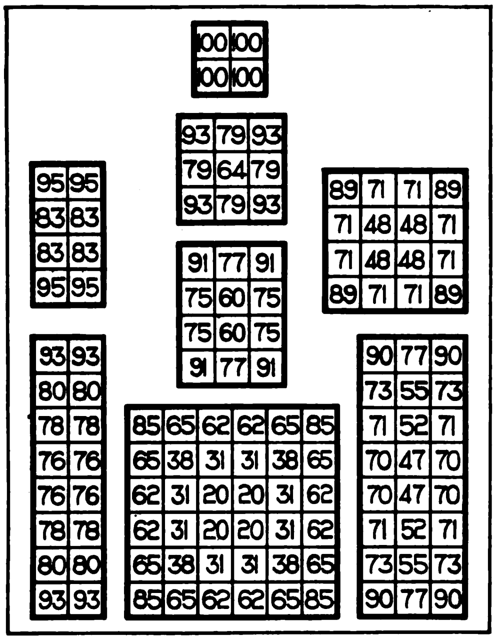
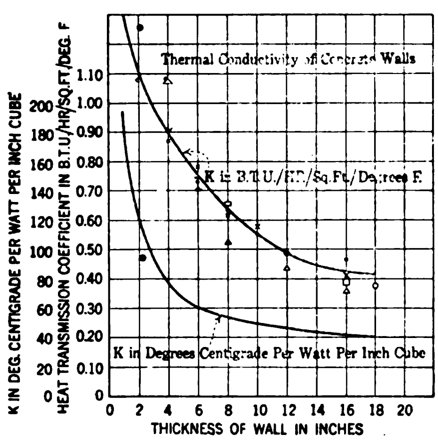


FIG. 22—RELATIVE WATT LOSSES FOR INDIVIDUAL DUCTS AND BANK OF DUCTS PER FOOT OF CABLE FOR SAME TEMPERATURE RISE (PER CENT OF 2 BY 2 BANK)



• N.Y. Edison Values
o Elements of Heating & Ventilating-A.M. Green-1916
▵ Heating & Ventilating Magazine-Feb. 1917 Data Sheet Heat Losses No
□ Heating & Ventilating Hobbard 1914
× U. of P. Values used by Department of Buildings & Grounds
• Mechanical Equipment of Buildings-N.S. Thompson-1915

FIG. 23

These tests conclusively dispose of the possibility of danger from all compounds operated at temperatures below 125 deg. cent.

6. VITAL IMPORTANCE OF AMBIENT TEMPERATURES IN SUBWAY DUCTS

Before making the final recommendations, I wish to bring out a point of importance, that the operator must carefully study the temperatures under which the cables will operate when placed in subway ducts, especially when the trunk lines contain many ducts and cables in one bank.

The paramount importance of carefully surveying the ambient temperature conditions in ducts is shown in Fig. 22 giving the relative allowable losses for a given temperature on each cable with different duct arrangements. In the figure, the losses in a bank of two by two ducts are assumed as 100 per cent.

The actual values of losses allowable per duct-foot will vary greatly according to the load factor, the thickness of the concrete wall surrounding the bank of ducts, and the amount of moisture in the soil. The thermal conductivity of concrete, as obtained by special tests by The New York Edison Company, is shown in Fig. 23, which also represents a compilation of results obtained by other authorities for different thicknesses of concrete. The variation in conductivity with thickness is probably due to the fact that surface drops were also involved.

The thermal conductivity of the soil under various conditions of moisture was determined with the following results:

Dry sand	90	deg. cent. per watt, per inch cube
Natural soil (approximately 6 per cent moisture)	39	
Natural soil with 9 per cent moisture added	19	

7. THE RECOMMENDATIONS FOR TEMPERATURE LIMITS

After having reviewed all of the foregoing data, including the Steinmetz and Lamme report, the British Engineering Standards Committee tests, the surveys of large operating companies, and all special tests and findings herein presented, I submit that the permissible operating temperatures of impregnated paper insulation, in which dielectric stress is low, are to be a function of the load factor at which the cable operates. The load factor for cables used in systems of distribution is intended to be the ratio between the yearly average load and the maximum load on the cable. It is certain that a load factor of say 33 per cent with seasonal winter peaks and correspondingly smaller maximum loads for the rest of the year will produce an average temperature on the cable considerably below 85 deg. cent., so that a limit of say 105 deg. cent. at peaks for 33 per cent load factors is unquestionably safer than 85 deg. cent. continuously, as allowed by the present Institute Rules. The proposed plan corresponds with the well established practise of rating electrical apparatus at a temperature rise of say 40 deg. cent. for continuous loads and from 55 to 65 deg. cent. for two or three hours overload. Machinery so designed has given excellent service for the last 25 years.

I should suggest for consideration for impregnated-paper, low-tension cables the temperature limits in function of the load factor of the cable, as follows:

105 deg. cent. for load factors	around	33 per cent
95 " " " " "	"	50 per cent
90 " " " " "	" over	66 per cent

The suggested temperature limits may perhaps be presented in a more general form by working back from the load factors to corresponding values of rise of temperature allowable for normal loads and overloads for specified hours. I *prefer to use the load factors* as they are fundamental in the determination of the most economical current density in cables as per *the Kelvin law which prescribes lower current density, and consequently lower losses and smaller temperature rise, the greater the load factor.* This gives a balance between economy and heat stress upon insulation. However, the important principle to be established is that the limiting temperature must be lower the greater the number of hours the insulation works at that temperature.

The shortcomings of the present Rules are that for cables they do not allow any rise of temperature for brief overloads above the 85 deg. cent. which is the limit for continuous operation, while they allow, for the same type of insulation in machinery, 105 deg. cent., continuous.

The Limitations of the Stop Watch as a Precision Instrument

BY A. L. ELLIS

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IN MANY scientific and engineering measurements the quantity, time, is an important factor. Its value may be required within widely varying limits of accuracy. A high degree of precision can of course be obtained with our present-day astronomical clocks in proper environment and their usefulness greatly extended by electrically relayed circuits. This method, however, is cumbersome, leaves much to be desired and is not generally applicable to laboratory measurements, not to mention the wide variety of field work. The result is, the more convenient stop watch is frequently the criterion used in judging intervals of from a few seconds to periods between appointments with the dentist.

Believing that the characteristics are not generally appreciated by the user, it is the purpose of this paper to point out the limitations of the stop watch in precision measurements. It will not be necessary to discuss such relatively classical adjustments as "isochronal" and "thermal," as errors due to these sources are entirely masked by those due to the principle of operation, mechanical restrictions, and design.

The several types of watches to be discussed will serve to illustrate the sources and character of the errors in those commonly used. Claim is not made that all types are shown nor is it the purpose of this paper to choose among the types.

Applications

A great majority of the stop watches made are sold to the non-technical public who put them to the use of an ordinary timepiece, and occasionally time sporting events. Obviously, they are designed and manufactured to meet the demands of this class of trade. As their use as timekeepers is of first importance, they are made in many grades. To these grades are added the start, stop, and reset mechanism of the sweep second hand, and which in the case of a given make, is the same for all grades. Therefore, the limitations of a given type of stop mechanism of a given make are the same in the low and high-priced watch.

As used by the technical public, the performance as a stop watch is the prime requisite. The accuracy of many scientific and engineering measurements is limited by stop watches' inaccuracies. Designed to meet the needs of the non-technical public, where the stop mechanism is used a few times a year, it is not robust enough to stand up under the demands of engineering tests, as for instance, the calibration of watt-hour meters, where a day's use exceeds several years non-technical use.

Experience of over twenty years in a manufacturing organization, with over four hundred stop watches, (including thirteen makes and nineteen models), shows that nearly all are in the repair shop every two months and in cases where the use is more nearly continuous, as in meter testing, operation tests, etc., the repair shop intervals do not exceed two weeks.

Cost Versus Time Keeping

The ideas of the technical public as to what constitutes the best stop watch vary greatly. Many think the more costly the better. That this view, when applied to a stop watch, is wrong, will be made evident.

One of the big factors of cost of a modern timepiece is the adjustments for running in any position. Essential to these adjustments are the jewels of the train. Where the adjustments are approximate, only a few are required. Where the adjustments are to be pre-

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cise, many are required and the cost is increased out of proportion. Precise adjustments cannot be made without many jewels and high cost, but it does not necessarily follow that with a large number and high cost one obtains precise adjustments; this idea is common as any jeweler can affirm, and accounts for the catch-penny watches of obscure make upon the market.

The function of the jewels, as you all know, is to reduce friction to a minimum, that the energy imparted to the balance may be the same with each tick, altered

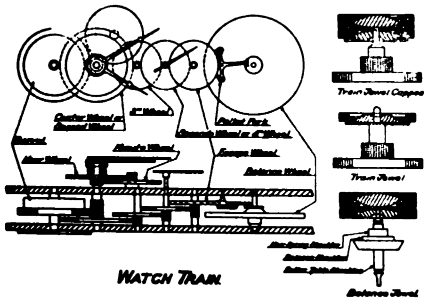

FIG. 1

as little as possible by the variable wear, as time goes on. The disposition of these jewels and their bearing upon the requirements of a stop watch will be considered.

A very important timekeeping requisite is that the balance in its oscillations shall swing unhampered in any way. This requirement is an inherent source of error for a stop watch and will be considered together with the jewels at this point.

Fig. 1 is a diagrammatic sketch showing the disposition of the principal parts to be jeweled. Starting with the wheel marked "barrel" containing the mainspring, the force of which acts through the center or second wheel, the third wheel, the seconds or fourth wheel, the escape wheel, the pallet fork arbor to the balance, the speed of revolution increases in the order named. The force acting upon the bearings to produce friction, however, is greatest at the slowest speed. The disturbance, due to friction and wear, is greatest on the fast moving bearings. The importance of jewels is greatest at the balance and diminishes as the barrel is approached. The practise varies greatly. The most common, and certainly the most important is a seven-jewel movement. These jewels are disposed two at each end of the balance staff, the roller jewel and the two jewels of the pallet engaging the escape wheel. Of the two at each end of the balance staff one acts to center the staff (ring stone), and the other to limit end play (end stone). Their general shape and the staff are shown at *A*. The diameters of the pivots are made as small as possible, in some cases 0.002-in. diameter, to reduce friction. The roller jewel in the roller table is of special shape, varying in different makes.

The next common arrangement is the fifteen-jewel movement obtained by adding ring stones to the bearings of the pallet fork, the escape wheel, the fourth wheel, and the third wheel.

Seventeen jewels are obtained by adding two ring stone jewels to the center wheel.

Nineteen-jewel movement is obtained by adding two jewels to the barrel between the barrel and its staff, or by adding two cap jewels to the end of the escape wheel staff. An additional number of jewels is obtained by adding caps to the remainder of the train.

Fig. 2 gives some of the more important characteristics of the modern escapement showing the escape wheel and its connection with the balance through the pallet and fork.

The escape wheel is shown locked against the pallet stone *R* at position marked "lock." The pressure of the mainspring at this point holds the fork against the upper banking pin.

The roller jewel marked "jewel pin" is shown carried into contact with the fork slot by the balance rotating in a counter-clockwise direction. Some of the energy in the balance wheel will be expended in carrying the fork through an angle of from one to one and a half degrees, the angle of lock, backing up the escape wheel against the mainspring. At this point the impulse face of the escape wheel club comes in contact with the impulse face of the pallet jewel *R* and energy is transferred from the mainspring to the balance carrying the pallet and fork against the lower banking pin, the jewel pin on the balance being released from the slot. The balance then continues free motion until its energy, minus that of friction, is

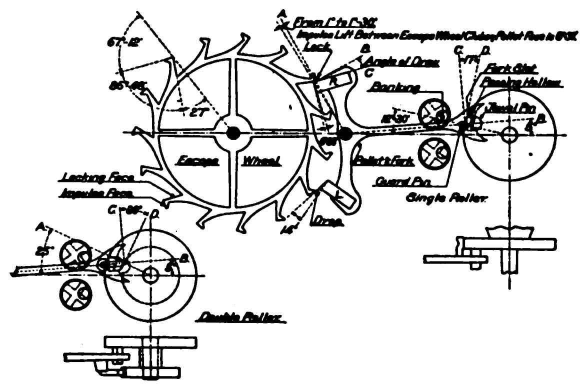

FIG. 2

transferred to the hair spring where the spring reacts to return the balance and the operations are repeated. The balance swings nearly a full revolution to the right and to the left from its position of rest. The actual excursion depends upon the force of the mainspring acting at the escapement, (friction losses in the balance and other moving parts, etc., are neglected). In general, the excursion of the balance is 680 degrees of motion. The roller jewel is in contact with the pallet and fork through 60 degrees of its motion. The pallet fork moves through an angle of ten degrees.

Of this angle, a degree and a half to two degrees are necessary for lock and drop. Through the remainder of the angle the escape wheel, and therefore the train are in motion. The corresponding angle of the balance wheel is from 48 to 51 degrees. From this it will be seen that the train has an intermittent motion, being in motion during the time that the balance swings through its center position at its maximum velocity. The train is in motion while the balance swings through

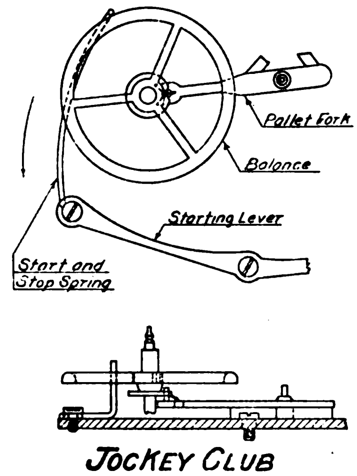

FIG. 3

0.07 of its excursion. The corresponding time is 0.01 of a second, the period of the balance being 0.2 sec. or a frequency of 18,000 beats per hour, 300 beats per minute.

Errors of a Mechanically Perfect Stop Watch

From the foregoing, it will be seen that the sweep second hand of a stop watch is in motion but a small part of the time during an observation. In timing an event the watch may be started just after the escape wheel has been released and stopped, just before the escape wheel is to be again released, in which case the time observed at the sweep second hand would be too short by one beat or $^1/_5$ of a second. The start and stop can also be so timed that the error will be one beat too much. Therefore, two mechanically perfect watches used to time the same event may disagree by $^2/_5$ of a second or 1.3 per cent in a thirty-second reading or both watches can be in error by half this amount plus or minus as the second limit.

Rate

Watches to be adjusted to keep time with extremely small variations must of necessity have many jewels. The cost of such a movement is not warranted in a stop watch. First, because the load to be carried by the train varies considerably whether the sweep second hand is running or not, and second, because careful adjustments made at the factory are almost invariably destroyed when the watch is repaired by the average jeweler.

An alarm clock without jewels can readily be regulated to keep time within one minute, in twenty-four hours. This rate for an interval of one minute, produces an error of ± 0.04 second. The inherent error of a mechanically perfect stop watch is five times this amount. While the rate of an alarm clock as used is sufficiently precise for use as a stop watch, it is true that it cannot be carried about without seriously disturbing the rate.

The addition of a few jewels properly applied as in the case of the seven-jewel movement removes this objection and permits even a closer rate adjustment. The addition of more than seven jewels serves only to reduce an already negligible error.

Errors due to Methods of Application of Start and Stop Mechanism and Mechanical Imperfections in some Typical Stop Watch Designs

The simplest, cheapest, and perhaps the most common stop watch is one without the usual hour and minute hands, having seven jewels. This watch, of Swiss make, is supplied to the trade under many names and models, differing slightly. The principle of operation is the same in all cases. The sweep second hand and minute hand, if any, are started and stopped by starting and stopping the balance.

Fig. 3 is a sketch showing how this is carried out in the type known as "Jockey Club." The balance and starting lever are shown in the stopped position.

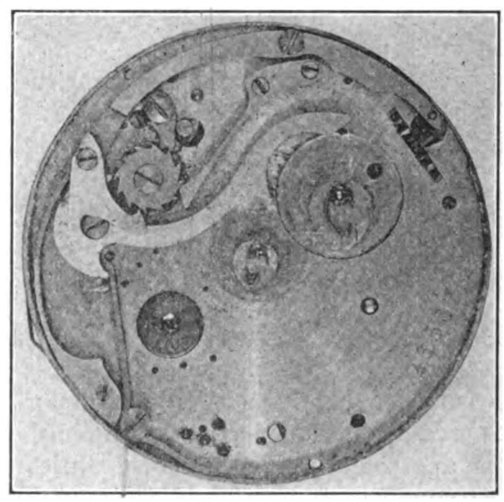

FIG. 4—JOCKEY CLUB
Under the dial with hands removed.

Pressing the stem, (not shown), starts the balance by snapping the starting lever about the right-hand screw, dragging the start and stop spring along the edge of the balance in the direction of the arrow, thereby setting the balance in motion.

Pressing the stem a second time stops the balance by returning the lever to the position shown.

Pressing the stem a third time returns the hands to zero by means of a "fly-back lever" and heart cams.

These are shown in Fig. 4, a view with dial removed. The sweep second hand is removed from the small heart cam in the center of the plate of the small minute hand from the large heart cam. The fly-back lever as shown is ready to return the hands to zero by striking these cams.

Frequent pounding of these cams by the fly-back lever which strikes a heavy blow enlarges the holes in the plate and in the heart cam sleeves, which are of brass, causing the sweep second hand to jump forward or backward on being started or stopped.

The heart cams and hands cannot be rigidly attached to the staffs in this type of watch, as returning them to zero position must necessarily move the whole train, therefore, they are friction driven. The C-shaped springs seen on the heart cams provide this drive. One end passes around a pin at the point of the cam and the other end passes through a slot in the sleeve, bearing against the staff which is slightly recessed to prevent the heart cams moving along the staff.

The C-spring is an additional source of error, for if tension is too weak it will not drive, and if too strong, friction with the staff causes a rolling action between spring and staff while being returned to zero, producing a torque between the two members at zero. This torque results in the sweep second hand jumping ahead or back upon starting, the direction depending upon whether the hand returned to zero from the right or left. This error increases as the holes in the sleeves are enlarged. It is seldom less than $^1/_5$, usually from $^2/_5$ to $^3/_5$, and frequently $^4/_5$ of a second or more.

Another source of error common to all types using heart cam return is due to adhesion of different amounts between the fly-back lever and each cheek of the heart cam. This causes the sweep second hand to be pulled ahead or back as the fly-back lever recedes when the watch is started. This error would still further be increased by the magnetization of the fly-back lever and heart cams. Once magnetized, it is practically impossible to remove the last trace of magnetism unless heating is resorted to, which is out of the question.

The magnitude of this error can be determined in a given case by repeatedly pressing the stem while the balance is prevented from running with the aid of a camel's hair brush, meanwhile noting the position of the second hand. The added error, due to the C-spring, must be noted while the balance is free, as shown by trial, after returning the hand to zero from the right and left.

Still another source of error present in all types to a greater or less degree is the effect of the jar due to starting and stopping operations upon the unbalanced sweep second member. This error may produce a movement of the hand forward or backward when starting or when stopping.

Perhaps the most serious error in this type of watch, certainly the most disconcerting one for the engineer, is due to the method of starting and stopping. It is problematical at what position of the balance swing the stop wire will interfere with the balance as the starting lever returns to the stop position. If the interference results in turning the roller jewel out of the fork so far that when started it will carry the pallet fork to the opposite banking pin, all well and good,

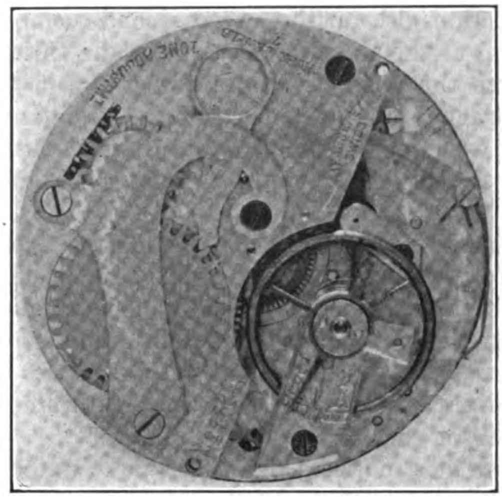

Fig. 5—Jockey Club

but it sometimes happens that when started, the roller jewel just returns to the fork without enough force to carry the fork over, and the watch does not start. More frequently the roller jewel returns to the fork with just sufficient force to carry it over, swinging a short distance beyond, with the result that an appreciable time is required for the balance to pick up to full motion. As the isochronal adjustment of these watches is in general very poor, considerable error results.

Fig. 5 is a back view of this type where the start and stop spring can be seen projecting slightly beyond the edge of the plate to the right. This picture gives a good idea of the general appearance and the relative positions of the starting lever and balance.

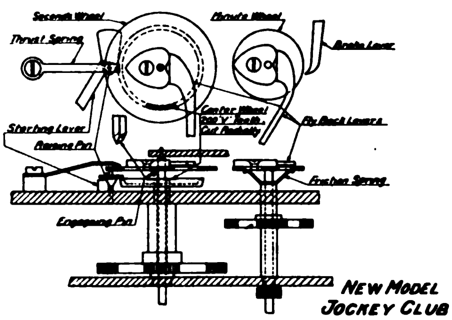

Fig. 6

Fig. 6 is a diagrammatic sketch of the new model Jockey Club. This model is without the usual hour and minute hands. The timing train runs continuously. The heart cams and hand are rigidly mounted on opposite ends of a staff forming the sweep second member. The staff of the seconds wheel of the tim-

ing train is a hollow and surrounds the staff of the sweep second member. The parts shown in the sketch are in position ready to start. The operations are as follow:

Pressing the stem, first removes the fly-back levers from the heart cams an instant before the starting lever moves away from the cone on the staff beneath the friction disk on the sweep second member. The removal of the starting lever allows the thrust spring to force the sweep second member downward until the engaging pin on the friction disk engages with the center wheel of the timing train, thereby carrying the sweep second hand forward in unison with the timing train.

Pressing the stem a second time returns the starting lever to the position shown, striking against the cone, elevating the raising pin, which, in turn, disengages the engaging pin and stops the second hand.

Pressing the stem the third time causes the fly-back levers to strike the heart cams, returning them to the position shown.

Errors most noticeable in this type of watch are due to play in the bearings of the raising pin, aggravated by the hammer blow action of the starting lever. The friction disk to which the heart cam is attached is clamped between the end of the raising pin and the thrust spring. During the process of engaging and disengaging with the center wheel, the downward motion of this disk forces the cone along the surface of the starting lever, resulting in a torque at the disk. This is further aggravated by the fact that the thrust spring, in moving up and down, produces friction that is not applied radially. These torques cause the sweep second hand to jump forward or backward when started and when stopped.

As previously pointed out, the timing train has 300 positions of rest per minute and is in motion 1/100th of a second in each 1/5 of a second. The center wheel has 200 V-shape teeth. If these teeth are adjusted so that the pin falls directly into the tooth space with the fork against one banking pin, it will not again fall directly into a tooth space until the fork has made three trips.

The magnitude of these errors can be observed by repeatedly pressing the stem while the fork is held against each of the banking pins in succession. An additional difficulty is met due to the action of the brake lever on the minute wheel. This wheel is driven by a friction spring to the minute wheel of the train. The hook end of the brake lever is applied to ratchet teeth at the edge of the minute wheel holding it against the operation of the train through the friction spring. If the torque of the friction spring is too great, the motion of the balance will be greatly reduced. If too small, it will not drive.

Fig. 7 is a view of the back of the watch showing clearly the relative positions of the fly-back lever, heart cam friction, disk and spring.

Another method for starting and stopping the sweep second hand is one in which the sweep second member carries a toothed wheel. An intermediate shaft carrying a coarse tooth pinion at the lower end, engaging with the fourth wheel of the train running with it continuously, carries at its upper end a fine toothed

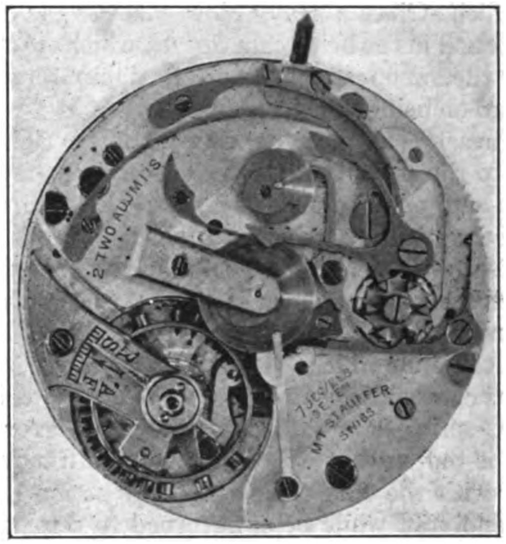

Fig. 7—New Model Jockey Club

pinion. This pinion is engaged with the toothed wheel to start, and disengaged to stop the sweep second hand.

Fig. 8 is a diagrammatic sketch of a watch of this type known as New York Standard. This type of watch has in addition to sweep second hand, the regular hour and minute hands.

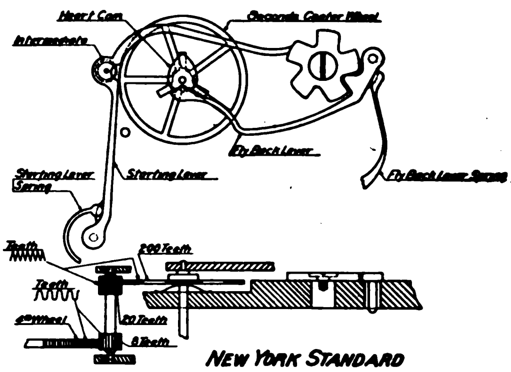

Fig. 8

Parts are shown in position ready for start. The operations are as follow:

Pressing the stem the first time turns the cam wheel, raising fly-back lever from heart cam just before intermediate is allowed to fall into mesh with the center seconds wheel starting sweep second hand.

Pressing the stem the second time disengages intermediate, stopping second hand.

Pressing the stem the third time allows fly-back hammer to strike heart cam, returning second hand to zero (position shown).

Sources of error in this type of watch are due to necessary play between the coarse tooth pinion and the fourth wheel, and play in the bearings of intermediate shaft. This amounts to $^4/_5$ of a second or more. The magnitude can be determined by putting parts in the running position, and with the balance stopped

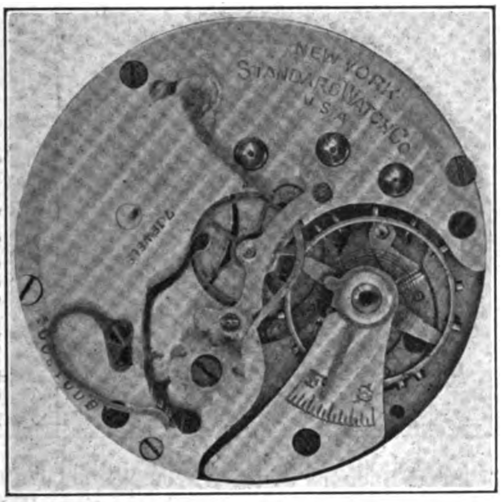

Fig. 9—New York Standard

note freedom of sweep second hand necessary to take up lost motion to fourth wheel. If it were not for the three-legged friction spring, the sweep second hand would whip back and forth by this amount with each beat of the watch. The error due to this cause is uncertain both as to magnitude and sign within the limits specified.

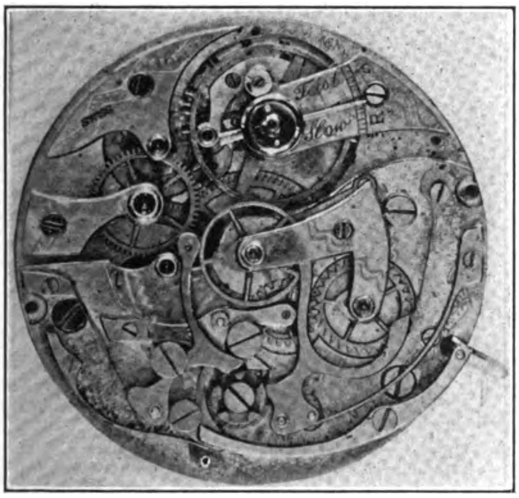

Fig. 10—Swiss Watch
With similar acting parts to the New York Standard.

Additional errors are due to the seconds center wheel having 200 teeth, while the intermediate has 300 positions of rest.

The intermediate gear strikes the same point on the seconds center wheel each time at starting.

Constant operation causes teeth to be deformed and produces jumping of the sweep second hand upon starting.

A jar on starting and stopping affects the sweep second member.

Fig. 9 is a back view showing the relative position of intermediate, starting lever, fly-back hammer, and tooth wheel, on sweep second member.

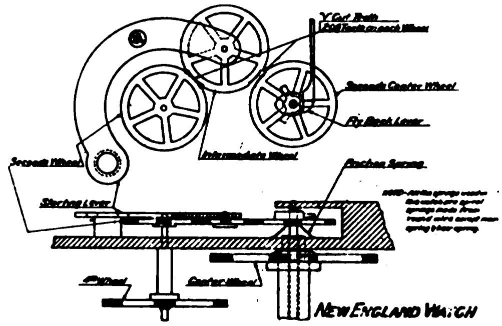

Fig. 11

Fig. 10 is a more complicated movement of the same type, of Swiss manufacture. This movement has, in addition to the sweep second hand, a minute counter advanced upon the completion of each revolution of the sweep second member. This is a regular fifteen-jewel movement with the addition of two ring stone jewels on the upper staffs of the sweep second member, and minute counter staffs, probably for appearance only as similar jewels are not found upon the lower ends.

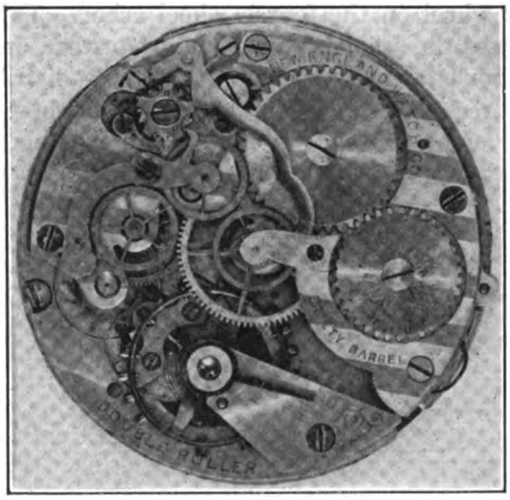

Fig. 12—New England Watch

In another type of movement the sweep second member is started and stopped by an intermediate gear running continuously with a similar gear mounted on the fourth wheel arbor above the back plate. The intermediate gear is thrown into and out of mesh with a tooth wheel on the sweep second member.

Fig. 11 is a diagrammatic sketch of a watch of this type known as the New England. Sequence of operations is the same as described for the New York

Standard type. The principal errors in this movement are due to 200 V teeth being used on all three wheels while the balance has 300 positions of rest. The intermediate gear strikes the same point on second center wheel deforming the teeth. Play in teeth of intermediate, and center play in the teeth between intermediate second center wheel and seconds wheel, which

FIG. 13—ALLION À VERSAILLES
For aviation in France.

has to be quite as large as the intermediate, is carried bodily about a pivot located not at the center of the seconds wheel. The intermediate in engaging with the center seconds wheel is made to rotate about the seconds wheel on the fourth wheel arbor. This usually causes the second hand to jump forward or backward upon starting, depending upon the distribution of the three wheels in different types of watches. This jump is augmented by the errors previously noted and frequently amounts to $^2/_5$ of a second.

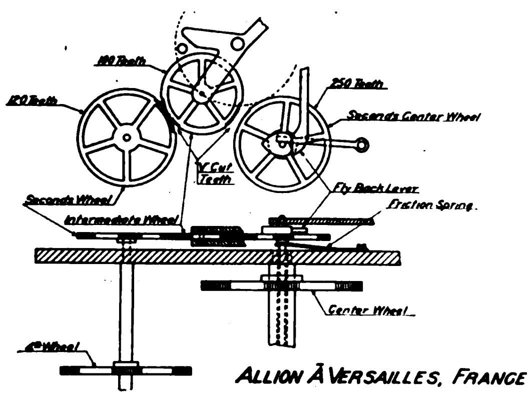

FIG. 14

Fig. 12 is a back view showing the relative position of seconds wheel intermediate, center seconds wheel heart cam, and fly-back lever.

Fig. 13 is a Swiss movement of a similar type, showing the relative positions of parts.

Fig. 14 is a diagrammatic sketch of the same watch known as "Allion a Versailles," France. The criticism of the New England watch applies to this type.

It will be noted that the intermediate swings about a pivot, less favorably located for accuracy, and that

FIG. 15—SPLIT SECONDS SWISS WATCH WHICH HAS ONLY THE TWO SWEEP SECOND HANDS AND MINUTE HAND
The parts shown here control one sweep second hand and the minute hand. Balance runs all the time.

the number of teeth is still not in agreement with the train positions of rest. The majority of the high-grade watches, (by that meaning high price) follow this general principle of operation.

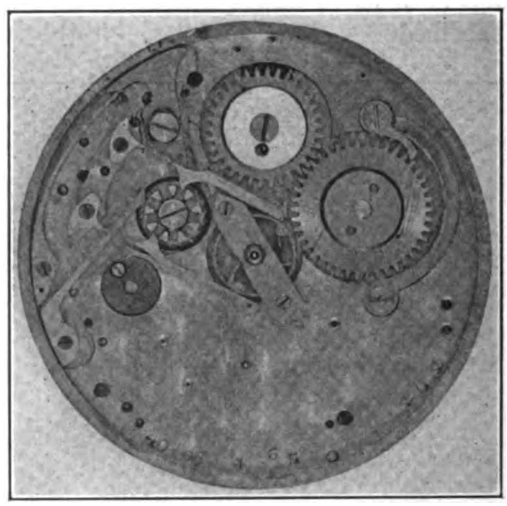

FIG. 16—SPLIT SECONDS SWISS WATCH
The parts shown here control the second sweep second hand. The function is to stop the hand, and release to continue in step with the other sweep second hand to a point at which it is to be stopped again. In other words this hand can only be stopped or released to run with the other sweep second hand.

Another principle of operation is that a small intermediate is made to engage with seconds wheel and second center wheel.

Fig. 15 is a back view showing the distribution of parts of a split second timer without the usual hour

and minute hand. It shows clearly the imitation compensated balance.

Fig. 16 is a view with the dial removed showing the distribution of parts necessary to operate the secondary sweep second hand that can be stopped independently of the main hand.

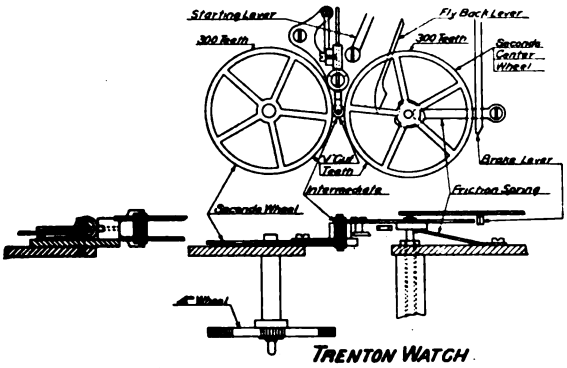

Fig. 17

Fig. 17 is a diagrammatic sketch of a watch of this type known as the Trenton watch, manufactured in this country many years ago.

The starting and stopping operations are as follows: Parts are shown in the running position. Pressing the stem the first time stops the sweep second hand by causing the starting lever to move to the left, striking the upper edge of the disk clamped to the staff supporting the intermediate, thereby turning the intermediate about this staff out of contact with seconds center wheel. This event takes place an instant before the brake lever falls in contact with the seconds center wheel, thus securely holding the sweep second member in position.

Fig. 18—Trenton Watch

Pressing the stem the second time causes the sweep second member to return to zero position by the fly-back hammer striking heart cam, the brake lever having been removed from sweep second member an instant before.

Pressing the stem a third time starts second hand by removing the starting lever from the disk on the intermediate, allowing the intermediate to engage, the fly-back lever having been removed from heart cam an instant before. In this watch it will be noted that the seconds center wheel and seconds wheel on fourth

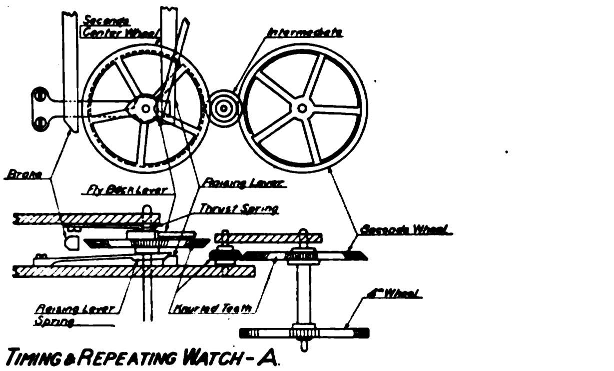

Fig. 19

wheel arbor have each 300 V-teeth; the error due to this source is consequently negligible.

The source of errors in this type are due to the intermediate striking at the same point on sweep second member repeatedly at start and end play in the supporting member. Movement of staff of sweep second member, due to application of either brake or intermediate upon stopping or starting, causes the hand to jump forward or backward. This is due to the necessity for clearance between the staff of the sweep second member and the hollow staff of the train, having no bearing provided above seconds center wheel.

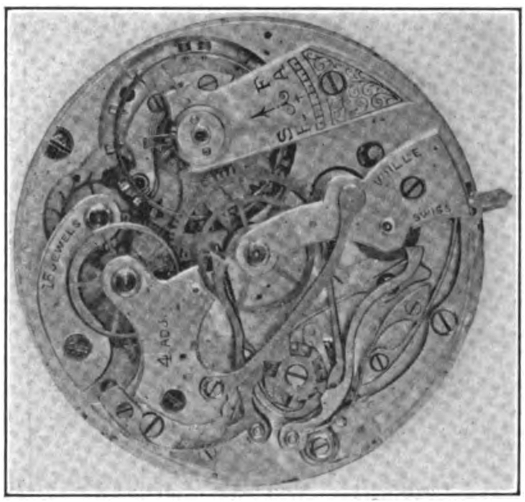

Fig. 20—Timing and Repeating Watch—A

The difficulty met with in adjusting this watch is due to necessity for play in the support of the intermediate. Without this it would be impossible to have the upper edge of the intermediate engaged with the seconds center wheel at the top to the right, and at the same time with the seconds wheel at the bottom to

the left, and remain engaged while the wheels make a complete revolution.

Fig. 18 is a back view showing the relative positions of parts.

Fig. 19 is a diagrammatic sketch of another type known as "Timing and Repeating," in which parts are shown

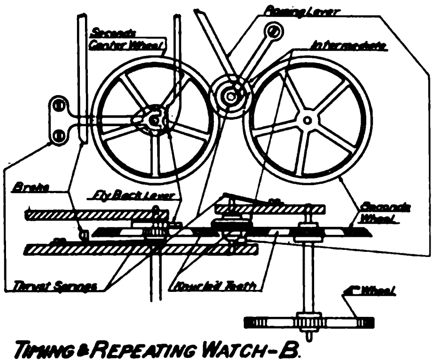

Fig. 21

in the stopped position, ready for starting. The operations are as follows:

Pressing the stem the first time removes the fly-back lever from the heart cam just before the raising lever is removed from beneath the raising lever spring, allowing the thrust spring to force the second center wheel into contact with the intermediate, carrying it also in contact with the seconds wheel.

The principal source of error in this type is due to teeth being knurled. The number is indefinite. The intermediate strikes repeatedly at the same point at start. The thrust spring bears on sweep second mem-

Fig. 22—Timing and Repeating Watch—B

ber at all times; the result is that unless the wheels are nearly perfectly true, the watch stops because there is not sufficient power in the train to force the sweep second member up against the thrust spring. The starting and stopping are accomplished by raising and lowering the sweep second member. The method described produces torques, causing the sweep second hand to jump forward or backward when started and when stopped. The extent of this error is in general 2/5 of a second and frequently more.

Fig. 20 is a back view showing the relative positions of parts. This watch has regular hour and minute hands in addition to sweep second and minute counter.

Fig. 21 is a diagrammatic sketch of a later model of the same make in which the starting and stopping are accomplished by raising and lowering the intermediate. This is a marked improvement over the previous model as it avoids the necessity for raising and lowering the staff carrying the sweep second member. With this exception the errors remain as in the previous model.

There is, however, a difficulty met with in adjusting the tension of the thrust spring at the top of the intermediate and beneath the seconds center wheel so that the former will have sufficient torque to oppose the latter and at the same tine carry the intermediate into contact with the seconds wheel. Any irregularity in either of the large wheels causes slipping. The freedom that must be allowed for the bearings of intermediate, second wheels, and center second wheel, causes a wedging action due to springs and rotation of parts. Any inequality in the teeth of the big gears will force a pair of members out of contact, and slipping results. This source of error is difficult to discover. For this reason, and for many others, at least two watches should be used for timing all observations.

Conclusions

Due to inherent errors of timing train, and those due to mechanical limitations and design, practically nothing is gained in accuracy by increasing the number of jewels beyond the standard seven-jewel movement.

An attempt has been made to reduce the inherent error in at least one instance by increasing the rate of vibration of the balance, but the price at which it was offered was out of all reason considering the accuracy gained and the cost of manufacture.

Some of the larger errors do not follow the law of probability, for while the errors may be either plus or minus, and vary somewhat in magnitude, some at least depend upon the interval of time being measured, as for instance, in the case of the Jockey Club type of stop watch if the interval being timed is less than thirty seconds, the hand will jump forward upon being started again. If the interval is more than thirty-five seconds the hand will jump backward on starting again.

The sources of error in a watch are such that at least two watches should be used simultaneously for timing an event, timing intervals of varying length if possible, the mean of all observations to be taken.

The stop watch applied to engineering measurements is not sufficiently robust for the purpose, and it is to be hoped that manufacturers will make a special effort to produce a stop watch suitable for this class of service.

Notes on the Effect of Heat on Impregnated Paper from Cable Insulation

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THE tests outlined below were made to determine at what temperature marked deterioration in the paper of impregnated paper cable took place. There are many shots well off the target in these results, although the average were determined from something over six hundred readings. Anyone who is familiar with the manufacture of paper and with the handling of it, knows the wide variation which occurs in different parts of the same sheet. The maximum tensile strength in a series of tests is frequently twice the minimum.

The first series of tests was started in December, 1917, and completed nine months later.

The sample was three-conductor cable, lead-jacketed, 4 ft. long, with 00 cylindrical conductors, saturated with a compound composed of resin and petrolatum. The paper wall on the individual conductors was 9/32 in. of 0.005 Manila paper and the overall jacket was 7/32 in. of 0.008 Manila paper; lead jacket 1/8 in. The sample was cut from a cable coming through in the regular course of production and was representative of ordinary manufacturing practise.

A narrow section was cut off and six strips of paper from the outer jacket were unwound and tested for tensile strength. The distance between jaws was approximately 7 in., rate of separation 20 in. per minute, average tensile strength 7343 lb. per sq. inch. Each end of the cable was then sealed and it was placed vertically in an oven. This oven had the following temperature cycle:

From 7 a. m., Monday, to 12 noon, Saturday, average temperature ran from 68 to 74 deg. cent. Steam was shut off at 12 oclock, Saturday, and by 6 a. m., Monday, the temperature had dropped to 30 deg. cent., when the steam was again turned on.

At different times short sections were sawed off from the sample, and the sample resealed and put back into the oven. The results showed average tensile strength given in Table 1.

TABLE I
Average Tensile Strength per Sq. Inch

Not heated	1 mo. bake	2 mos. bake	4 mos. bake	6 mos. bake
7343 lb.	7816 lb.	7338 lb.	7088 lb.	8290 lb.

The above samples were from the outer jacket. Samples of paper from the individual conductors showed similar results. Samples were also bent and twisted in the fingers to detect brittleness.

To be presented at the 9th Midwinter Convention of the A. I. E. E., February 16-18, 1921.

The same sample that had the six months' bake, with each end sealed, was then placed in an oven at a temperature of 100 deg. cent. At the end of the first month the average tensile strength was 7240 lb. per sq. inch; at the end of the second month, 7173 lb. per sq. inch.

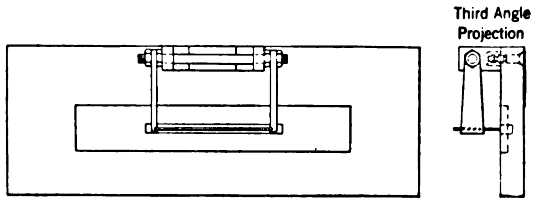


FIG. 1—APPARATUS FOR MAKING BREAK-DOWN VOLTAGE TESTS ON NARROW STRIPS OF INSULATION—PLAN AND ELEVATION

In the spring of 1920 another test on the same size and insulation was undertaken. In this case, seven samples were cut from one length of cable coming through in regular production. Each end of each sample was sealed. Sample A was held as a check; sample B was heated for 30 days at 100 deg. cent.' sample C was heated 60 days at 100 deg. cent., sample D—90 days at 100 deg. cent., sample E—30 days at 110 deg., sample F—60 days at 110 deg., and sample G—90 days at 110 deg. On each of the paper samples a break-down test was made, using the so-called knife-blade apparatus shown in Fig. 1.

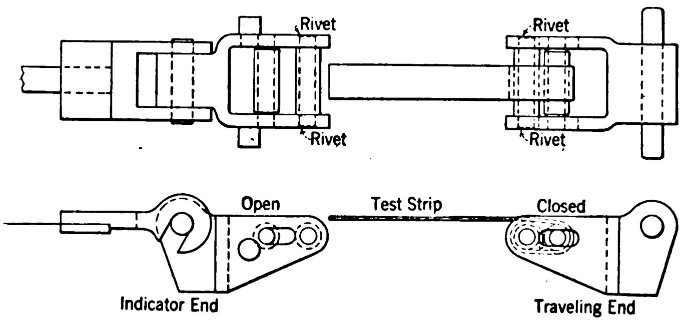


FIG. 2—GRIPS FOR MACHINE FOR TESTING TENSILE STRENGTH OF CABLE PAPER

Straight tensile strength tests were made, and in addition tensile strength tests were made where the stress applied to one edge of the paper was greater than the other. Paper was folded over the rollers of the grip shown in Fig. 2, the roller at one end being slightly tapered, thus applying greater tension to one edge than to the other when the jaws were separated. The average results of these tests are shown in Table 2.

TABLE II

	Break-down volts per mil	Breaking strain lb. per sq. inch	Tearing strain lb. per sq. inch
A —Jacket	420	9000	6833
Singles	380	9600	6666
B —Jacket	375	9000	6833
Singles	340	10333	7600
C —Jacket	320	6666	4500
Singles	410	7600	5466
D —Jacket	360	7000	3667
Singles	360	6933	4266
E —Jacket	333	6833	3500
Singles	360	7200	4666
F —Jacket	300	5016	2166
Singles	310	5333	3466
G —Jacket	300	5000	2500
Singles	320	5333	4133

We note from this table that the ratio of tearing strength to the average breaking strength in sample A, cable not heated after manufacture, is 0.72; in sample D, heated 90 days at 100 deg., 0.57, and in sample G, heated 90 days at 110 deg., 0.64. This shows definitely that the tensile strength of the paper deteriorates less rapidly than its resistance to tearing. The higher rate of deterioration at 110 deg. cent. is clear and is well marked by comparing the results from sample D, 90-day bake at 100 deg., with sample E, 30-day bake at 110 deg., the deterioration in 30 days at 110 deg. being practically equal to deterioration in 90 days at 100 deg. From these results, we can say in a preliminary way, that deterioration at 70 deg. cent. is negligible; at 100 deg. is marked in 90 days; at 110 deg. is marked in 30 days, applying to the particular quality of paper and impregnating compound which were under test.

A load with a two-hour peak, allowing such peak to occur for 30 days in each year, would give 60 hours yearly operation at maximum temperature, which we will assume at 100 deg. cent. It is evident that the cable on this basis could be used for many years, operating at 100 deg. cent. as its peak temperature, before reaching the stage of deterioration obtained in the 90-day test at 100 deg. cent. It is, of course, impossible to state the exact time because we do not know the rate of deterioration at temperatures below 100 deg. cent.

From an examination of the cable and paper taken from sample G, there is no question in the writer's mind but that cable with paper in this condition would be perfectly safe for operation at low voltages. Further the writer believes that cable so treated could have been withdrawn from conduit and reinstalled. Briefly, the temperature limit fixed for the operation of a low-tension cable, to avoid undue deterioration, must take into consideration the length of time during which temperature is maintained.

APPENDIX

Tensile Strength

The samples for testing are taken from the finished cable after it is leaded. In case of a multiple-conductor cable, part of the samples are taken from the overall jacket and part from each of the individual conductors. If the strips are over ¾ in. wide, they are cut to ¾-in. width with a steel straight edge and a sharp pointed knife. The jaws of our testing machine will not take strips over ¾ in. wide. The test strips should be about 12 in. long so that the distance between jaws will be about 7 in. When the strips are placed in the jaws, it is important that they are put in straight, so as to get a straight pull. The jaw travels at the rate of 20 in. per minute, the machine used being our standard rubber testing machine which registers the pounds pull when the sample breaks.

Tearing Test

This test is made the same as tensile strength except that the back roller in the traveling jaw has a taper of 0.025 in. per inch. When the tearing test is made, the straight roller is taken out of the movable jaw and the taper roller inserted in its place.

Creasing Test

Samples of paper as described for tensile strength test are looped back on themselves and flattened down with a 10-lb. weight placed over the loop for a period of one minute, thus making a crease in the paper. This method is used in order to make a uniform crease in all samples. The strips are then straightened out and put into the machine using straight rollers in the jaws, and the tensile strength measured.

The jaws used for making the tests are shown in Fig. 2.

THE YEAR'S PROGRESS IN RADIO TELEPHONY

In connection with research work at the Bureau of Standards on radio telephony, it is necessary to keep in touch with progress in this subject elsewhere. A review of recent developments and achievements has been prepared for publication in the *Electrical World.*

The past year has witnessed steady progress and increasing public interest in radio telephony. Voice transmission by radio waves has advanced from the experimental stage to established practise, for distances of a few hundred miles, and since all inherent difficulties have been surmounted, it is actually possible to carry on reliable radio telephony over as great a distance as ordinary wire telephony. It seems probable that commercial telephony across the Atlantic will be an established fact in the not far distant future. The quality of transmitted speech or music is as perfect as in ordinary wire telephony.

Regulation of Frequency for Measurement Purposes

BY B. H. SMITH

Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

IT happens very often that it is desirable or necessary to transmit a quantitative indication to a more or less remote point. For instance, in a modern power system with its various sources of power, the load despatcher may wish to know the amount of power generated in a station perhaps several miles away, so that he may be able to better distribute his load. In addition, it may be desirable to regulate automatically the distribution of power as well as limit the amount that is received from a distant point. In this connection the problem may not be simply that of limiting the indicated power but of measuring and limiting the integrated demand over a definite time period. Of a different nature is the problem of recording at widely distributed points various operations in an industrial plant so that the results can be compared on the basis of the exact time of occurrence. satisfactory performance giving accuracy and high torque has been developed, making use of the automobile speedometer principle of a revolving magnet acting on an aluminum disk.

The purpose of this paper is to consider a number of metering systems where the frequency of a circuit is controlled in order to transmit an electrical condition to a remote point and to bring out the adaptability of this quantity for such purposes.

In 1917 the C. M. & St. Paul R. R. was confronted with the problem of measuring the power consumed on its latest electrified section extending from Tacoma and Seattle for a distance of about 200 miles east. It was decided to measure the power received at the various substations, Taunton, Cedar Falls, and Renton, and transmit the measurements to the dispatcher's office where they would be totalized and recorded.

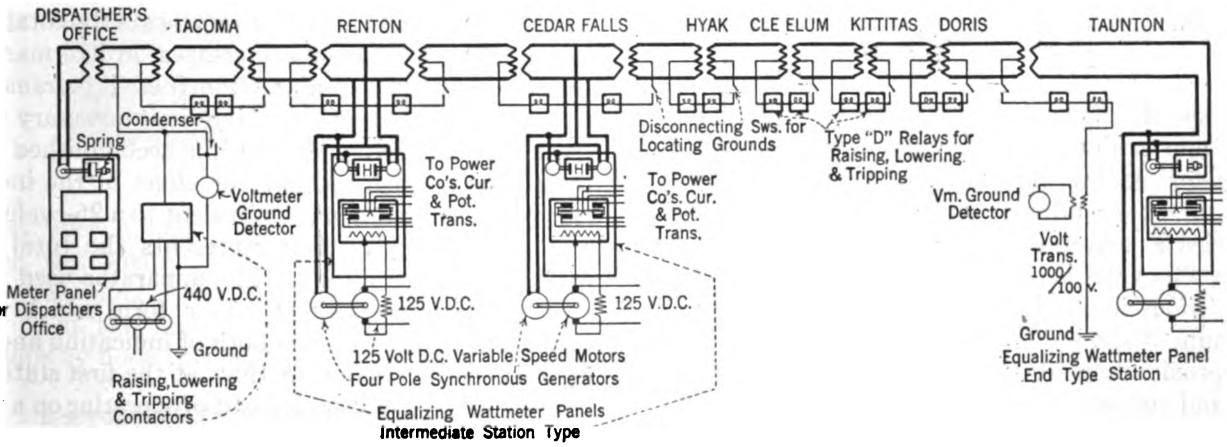


FIG. 1—DIAGRAM OF POWER INDICATING AND LIMITING SYSTEM, CHICAGO, MILWAUKEE AND ST. PAUL R. R. CO.

For all of the above problems frequency lends itself as a quantity which can be made proportional to a given indication and transmitted without any change for practically any distance. In this respect it stands out as being far superior to the transmission of energy or voltage or current. The transmission of voltage is affected by resistance in circuit, the transmission of current is affected by leakage and induction and the transmission of energy is affected by both of these quantities. Frequency is not affected by any of these quantities. The only problem is its satisfactory control and measurement. The speed control of a small motor-generator set to give a desired speed within wide limits has been accomplished with more or less success in the past, but the frequency meter in its ordinary form is quite unsuitable for accurate measurement purposes. A new type of frequency meter of most

For much of the distance the climatic conditions are very severe and, especially along the coast, the weather is so wet that leakage of electrical energy from any kind of outdoor circuit is very great, and any method making use of quantitative transmission of current is out of the question.

The use of frequency was proposed as a suitable method, because frequency is a quantity which can be carried over a long distance without being subject to changes, and the details of the apparatus as installed some months ago are perhaps worthy of our attention as being an example of the most extensive application of the use of frequency for measuring purposes in service up to the present time. First of all, it is necessary to obtain from some source which will allow of regulation a frequency which can be made proportionate to the measured power. This is accomplished by connecting a wattmeter to a small a-c. generator in such a way that the speed, and hence frequency of

To be presented at the 9th Midwinter Convention of the A. I. E. E., February 16-18, 1921.

the generator, is proportionate to the power received. This is done as follows:

At the first substation, Taunton, a small synchronous motor is driven from an a-c. generator, and through a revolving magnet acting on an aluminum disk produces a torque which over a wide range is proportionate

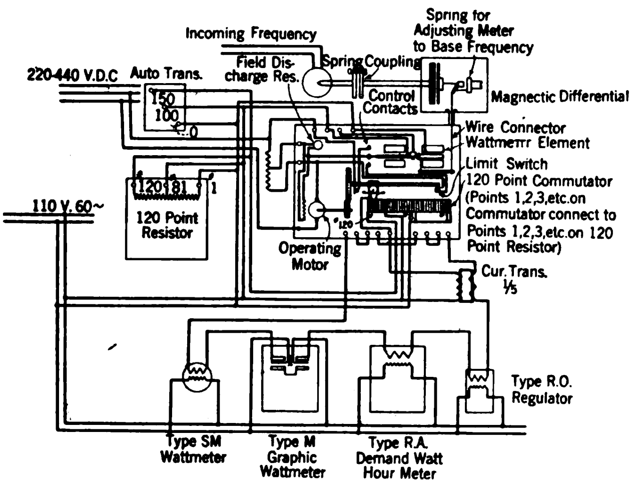


FIG. 2—DIAGRAM OF DISPATCHER'S OFFICE POWER INDICATING AND LIMITING SYSTEM

to the speed. This torque is balanced with the wattmeter and maintained so that with any change in wattmeter reading the speed changes accordingly.

To take care of zero load a "base" frequency of 25 cycles is maintained, so that if the load is zero, exactly 25 cycles is sent out to the next station, and with various loads the frequency is increased up to a maximum of about 60 cycles. The outgoing frequency at approximately 100 volts is transformed to 2000 volts and transmitted to the next station. Here, and at three more stations, at intervals of about thirty miles there is no power received and the lines are

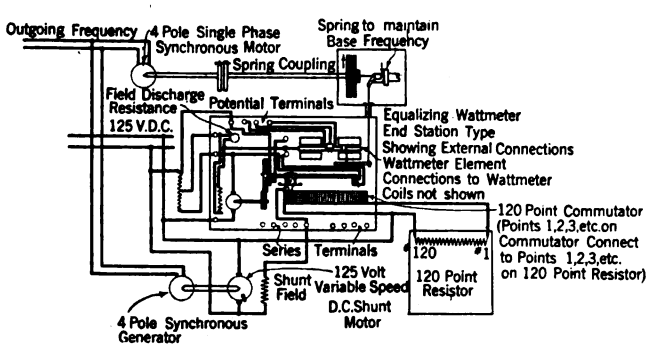


FIG. 3—DIAGRAM OF END STATION METER POWER INDICATING AND LIMITING SYSTEM—CHICAGO, MILWAUKEE AND ST. PAUL R. R. CO.

brought into the station only for the purpose of bringing out the phantom or power control circuit which will be mentioned later.

At the fifth station, Cedar Falls, the frequency is increased by an amount proportionate to the power being received at that station. It is not done directly however, but another generator is introduced and so controlled that its speed corresponds to the incoming frequency plus any power coming in on its own meter. The incoming frequency operates a synchronous motor similar to the one at Taunton and shown as the left hand motor in Fig. 8, its effect is added to the power

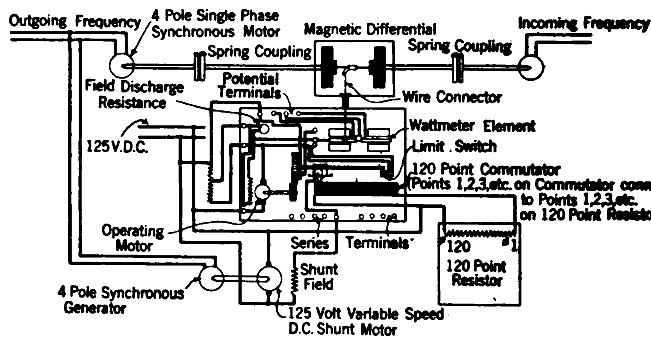


FIG. 4—EQUALIZING WATTMETER, INTERMEDIATE STATION TYPE, SHOWING EXTERNAL CONNECTIONS—POWER INDICATING AND LIMITING SYSTEM

incoming at Cedar Falls, and the outgoing frequency is balanced against it so that it represents the total power so far. The frequency is increased in like manner at the next station, Renton, and from there it is transmitted to the dispatcher's office. Here it is necessary to subtract the base frequency which is accomplished simply by a spring which opposes the effect of the incoming frequency by an amount equivalent to a 25-cycle speed, and the remainder then represents the total power received by the railroad. The apparatus used to convert the frequency effect into a form which can be shown on ordinary meters both of indicating and watt-hour types, is similar to that at the first station, but the control mechanism, instead of operating on a motor-generator set only controls the quantity of current in a local circuit through suitable slide resistance, and this current is passed through standard indicating, recording, integrating and demand meters.

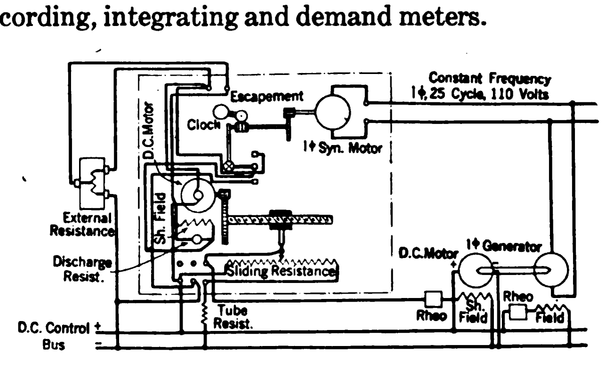


FIG. 5—DIAGRAM OF CONNECTIONS OF CONSTANT-FREQUENCY REGULATOR

It was mentioned above that at certain stations, the metering circuit was led in only for purposes of bringing out the power control circuit. This circuit is supplied from a 440-volt direct-current generator at the dispatcher's office. One generator terminal is grounded and the other is led into the frequency

circuit through the middle point of the 2000-volt transformer, then it divides between two wires and passes through the whole line to Taunton, where it is connected to ground as a return circuit. The experience to date with this circuit furnished the best evidence that quantitative measurement of a direct-current indi-

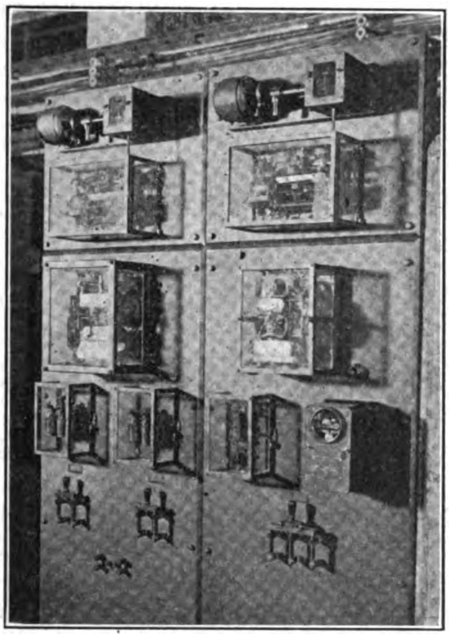


FIG. 6

cation over a long distance is out of the question under wet weather conditions. It was found in the very beginning, that about six milliamperes would leak from the line on an ordinary foggy morning. Perhaps by noon this leakage would entirely disappear.

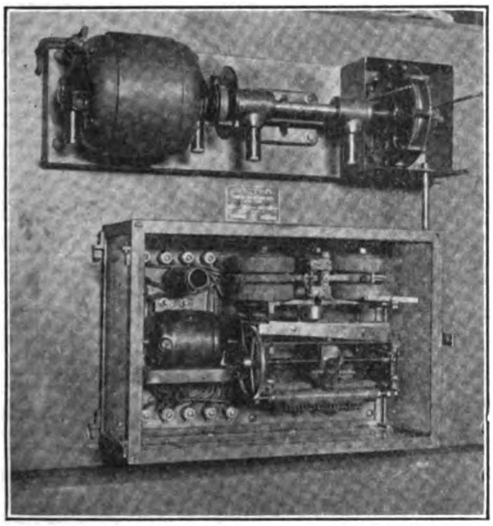


FIG. 7

This quantity is small but the control impulses sent over the line were only about 15 or 20 milliamperes, hence the percentage of leakage current was rather high. Later on there was evidence of much greater leakage, and at times it was impossible to get the proper control impulse through to the substations.

There was also found to be, especially along certain sections, a great deal of a-c. induction from the high-voltage power transmission line, and this tended to make the a-c. relays inoperative; but the effect on the metering frequency transmission was unnoticeable. This induction was, however, readily overcome by interposing in the circuit suitable resonant apparatus. It is not believed that the effects of ground potential have been serious, but recently there has been a great deal of apparent leakage from the 3000-volt power feeders into the circuit, so that the control impulses from the dispatcher's office at times are entirely overbalanced.

The transmission of the frequency indications, however, has been practically unimpaired under all sorts of conditions except where the line itself has been broken or accidentally grounded, and so far it can be said that this application of frequency control and transmission for metering purposes has more than met the expectations of all concerned.

Another application of frequency control of more recent date is being worked out in a large industrial plant. Here it is desired to record various operations

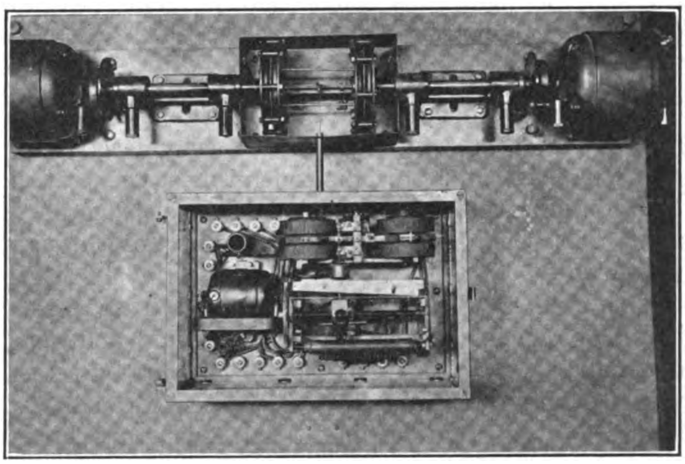


FIG. 8

in widely separated areas about the plant in such a way that indications can be compared on a basis of the exact time at which they occur. The timing mechanism of the various meters are operated by small synchronous motors and these are supplied from a circuit, the frequency of which is controlled by a master clock so that the integrated frequency is proportional to absolutely correct time. Thus at any point a synchronous motor can be connected to the circuit and with proper gearing made to drive clock hands or timing devices, and these will indicate with no error.

Fig. 5 is a diagram of the essential features of the control apparatus.

The speed of a small motor-generator set is balanced against a clock mechanism through a differential which operates the speed-controlling contacts. The differential is simply a sliding worm which moves forward

slightly when the speed gets ahead of the clock, and backwards, if the speed falls behind, thus operating the contacts so that the speed is brought back to the proper value. The correct speed and frequency thus obtained are transmitted to the various parts of the plant, and small synchronous motors operate the various timing devices. By this system there is ample power for a high-speed timing device, the various meters will agree with each other to within a small fraction of a second, and the whole system may be kept within two or three seconds of standard time. The central apparatus can be regulated for fast and slow speed in the same manner as a watch, and if after running for a length of time the system is found to be slightly fast or slow it can be speeded up or slowed down quickly by hand control and brought to agreement with wireless signals or other indication of correct time. Then a slight adjustment of the regulator will suffice to keep the system as nearly correct as can be expected from a good timepiece.

NOTES ON PROGRESS OF THE USE OF ELECTRICITY IN THE INDUSTRIAL AND DOMESTIC FIELD

BY P. H. ADAMS

Public Service Electric Co., Newark, N. J.

The use of electricity for industrial and domestic power purposes on a commercial scale began after the middle of the nineteenth century. In both of these fields it was first used for illumination, and several years passed before any other use was made of it. The development which followed the introduction of the electric light was such that it seems best to treat the two fields separately.

The Industrial Field

Gramme discovered in 1873 that one of his ring-wound generators would revolve when electrically connected to a similar machine operating as a generator. Little practical use was made of this knowledge until after 1880, when many improvements in motor design were made.

The first motors used were connected to series lighting circuits as well as to multiple circuits and were of small size. In one instance 18 motors in series were operated with the power required for one arc lamp. Motor drive for industrial sewing machines was one of the first applications to industry. Printing presses were also among the early motor-driven machines. The New York Gold & Stock Exchange used a three or four-horse power motor to drive about fifty tickers. This application was very satisfactory.

It is estimated that in 1886, there were about five thousand small motors in use in the United States.

The first Edison central station, that of the Edison Illuminating Co. of New York, was put into service in 1882, but there is no record of any motor load for industrial purposes on this station until the Edison motor was introduced in 1888. Four hundred and seventy horse power in industrial motors were supplied with power from this station in 1889. The first of these motors were used to drive printing presses. One of the motors put in service at this time was still in operation in 1912 and had cost only $25.00 for repairs during 22 years of service.

The growth of the use of electric power for industrial purposes was slow during this first decade, mainly because the art was in its infancy and discoveries and inventions, making the application possible, were just being made. The estimated total horse power of electric motors in service at the close of 1890 is placed at about 25,000 in the records of the National Electric Light Association.

Nikola Tesla and others introduced the polyphase generator and motor, making their first exhibition at the Frankfort Electrical Exposition in 1891. After a short period of development this type of equipment became the greatest factor in promoting the use of electric power in industry.

The development of the direct-current motor also advanced rapidly during this last decade of the nineteenth century and at its close the estimated aggregate horse power of electric motors in service is estimated at 495,000, an increase of about 1900 per cent in ten years.

This figure grew to more than 4,800,000 horse power by 1909, and the next five years saw another increase of over 80 per cent making a total of approximately 9,000,000 horse power in 1914. The estimated total as of January 1, 1920 exceeds 15,000,000 horse power, an increase of 3,000 per cent in 19 years.

The correction of the power factor of industrial loads has become of prime importance to the central station, and the static condenser, a commercial product of recent years, has come into wide use for this purpose. In this connection, the increased use of the synchronous motor for industrial drive is an interesting development. The rubber industry and many others are now using synchronous motors on a large scale.

Another new development is the electric shovel. This development provides a power shovel which can be used in almost any location. Electricity is now used in almost every phase of the steel industry. The fractional horse power motor has attained a wide application in the industrial field. Labor saving de-

vices for almost every conceivable purpose are now available, which do more and better work than hand labor ever accomplished.

Electricity is used to a greater or less extent in every part of the industrial field and its popularity, because of its economy, cleanliness and simplicity of application, is so great that the demand for motors and all other equipment now exceeds the combined output of all the manufacturers of electrical apparatus.

The Domestic Field

Benjamin Franklin, in 1749, demonstrated the fact that cooking could be done with electricity but almost a century and a half passed before practical use was made of this knowledge.

The electric fan was the first motor-driven device for the household and was used in the early eighties.

Heating devices came next, and in 1890 and '91, several companies began to produce heating and cooking devices of various kinds. Little, however, was accomplished in the commercial way until 1901 or 1902.

The advent of the efficient fractional horse power motor of today has caused the development of innumerable labor-saving devices for the modern home.

The second decade of the twentieth century has brought marked improvement in all household appliances and many new ones.

A partial list of the appliances obtainable today follows:

Motor-Driven. Washing machines, ironing machines vacuum cleaners, grinders, polishing machines, pianos, ice cream freezers, sewing machines, refrigerating machines, talking machines, dish washers, ventilating devices, and many others.

Stationary Devices. Ranges, heaters, toasters, fireless cookers, toilet devices, medical appliances, and others too numerous to mention.

The number of fractional horse power motors required for washing machines in 1920, by one large manufacturer, is over 500,000. This gives an idea of the extent to which the use of household devices has grown.

The total business in strictly domestic electrical appliance merchandise for 1920 may be conservatively estimated at five hundred million dollars.

The demand for fractional horse power motors is so great that delivery one year from the receipt of order is about the best that can be obtained. A similar condition exists in other lines of domestic appliances.

PERFORMANCE OF STARTING AND LIGHTING BATTERIES

In connection with the preparation of specifications for starting and lighting batteries requested by the Motor Transport Corps of the Army, the Bureau of Standards has made a brief study of the performance of these batteries in the operation of a few of the various types of automobiles; the experiments having been made on cars in ordinary running order.

Performance curves shown in the instantaneous demands upon the batteries when cranking the engines have been obtained by means of oscillograph records, these records showing characteristic differences typical of the design and condition of the various engines and starter systems. The initial values of current and voltage, which cannot be obtained by the use of ordinary indicating instruments, are shown at the time of closing the starter switch. After the starter has begun to turn, the current decreases rapidly, pulsating with the compression of the successive cylinders. An interpretation of the curves shows that much additional information could be obtained with respect to the operation of the starter system and the engine itself.

The results which have been secured are to be regarded as suggestive rather than quantitative measurements of performance. They indicate the possibility of using this method for the study of problems relating to lubrication, ignition, compression, and distributor action. In addition, an exact method is secured for measuring the speed from one revolution to another. The characteristics of the charging current when the engine was running were also studied. Measurements have been made at different speeds, different throttle openings, and different temperatures.

High-Current Tests on High-Tension Switchgear

BY PHILIP TORCHIO

Chief Electrical Engineer, New York Edison Co.

The article describes a series of tests on oil circuit breakers and disconnecting switches to determine their strength at brush contacts and supports in withstanding the mechanical stresses engendered by the magnetic flux due to the flow of large currents of the order of 100,000 amperes, as may exist at times of short circuits on large systems. Other tests were made on current transformers and potential transformer fuses.

For the first time, a synchronized motion picture machine and an oscillograph, were coupled to reproduce the coincident actions of the apparatus tested, and the variations of voltage and current in the circuit. The tests proved that practically all the circuit breakers then on the market had the brush contact placed in the wrong position, creating arcing before the operating mechanism had sufficient time to perform its function. The tests emphasized the importance of strong locks for disconnecting switches. Only single-turn primary-type current transformers and potential transformer fuses with resistance in series, were found adequate to give the service requirements.

THE high-current tests on oil circuit breakers, disconnecting switches, current transformers, and potential transformer fuses were carried out in 1918 and 1919 by the engineers and the Photographic Bureau of The New York Edison Company. The manufacturing companies lent effective cooperation in arranging the apparatus for the test, and in analyzing the results. For the first time, a synchronized motion picture machine and an oscillograph were coupled to reproduce the coincident actions of the apparatus tested and the variations of voltage and current in the circuit.

Oil Circuit Breakers

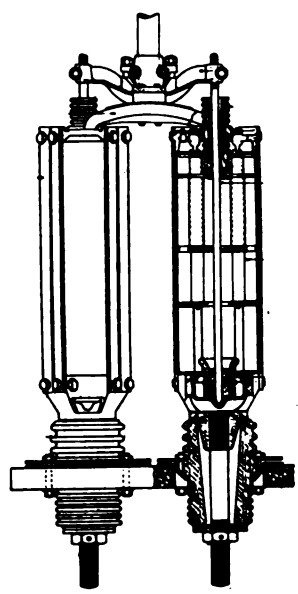
In connection with the study of very high-current electric welding apparatus, certain phenomena took place on the ordinary type of brush contacts, which prompted an investigation and subsequent tests to determine what would happen on the circuit breakers used in our central stations when subjected to currents of the order of 100,000 amperes, as may exist at times of short circuits on large systems.

The phenomenon which was noted was the well-known fact that when current is flowing in a closed circuit, the magnetic field set up by the current will tend to expand the loop outward. Therefore, if a circuit breaker is designed with a loop circuit so arranged that the mechanical pull due to the magnetic flux is to open the contact, the switch will present a weakness at that point; while if the movable contact parts are inverted so that the mechanical pull due to the magnetic flux is to force them more solidly against the fixed parts, the contact will be improved.

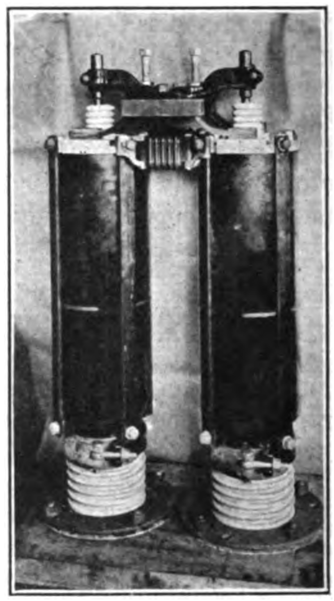
The circuit breakers tested were the *K*-52, *H*-3 and *H*-6 of the General Electric Company; and the *E*-9 and *O*-1 of the Westinghouse Electric & Manufacturing Company.

The tests proved that practically all the circuit breakers then on the market had the brush contact placed in the wrong position, so that when the current flowed the resultant mechanical force acted in a direction opposed to the brush pressure, thus tending to open the contact at this point; whereas, if the position of the contact brushes had been reversed, the mechanical force due to this current would have been exerted in the same direction as the brush pressure, thereby tending to improve the contact.

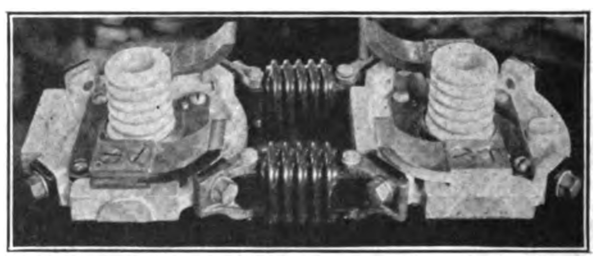
In addition to the force exerted at the contacts, it was found that the repelling force between contact supports was of such magnitude as to distort, and in some cases permanently displace, these parts.



1-A



1-C



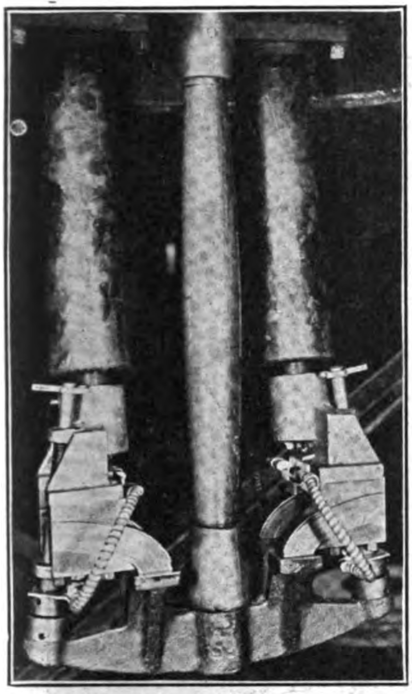
1-B

Fig. 1—G. E. Co. Type F H-3 Oil Circuit Breaker Showing Improvements

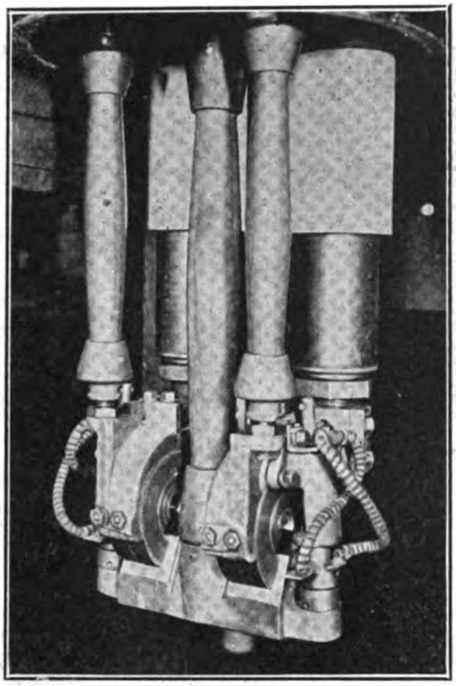
1-A. Original standard construction of contacts.
1-B. Detail of new inverted contact brushes and tie insulators.
1-C. Assembly of new inverted contacts and tie insulators.

In all these tests, the *circuit breakers were locked in the closed position. The arcing, therefore, was caused by the opening of the main and arcing contacts due to*

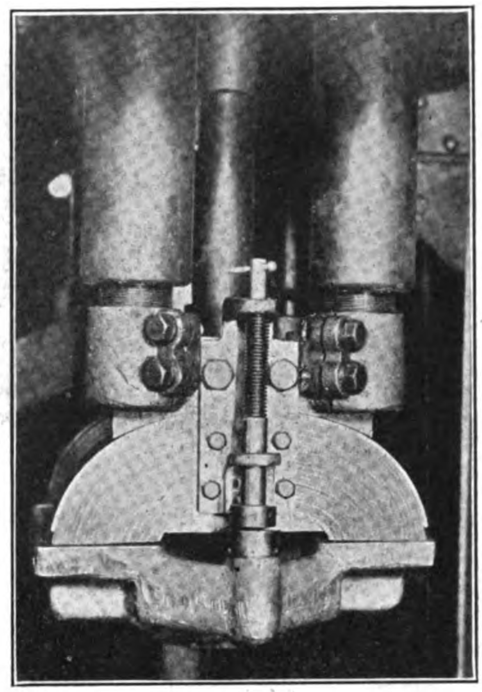
To be presented at the 9th Midwinter Convention of the A. I. E. E., February 16-18, 1921.



2-A



2-B



2-C

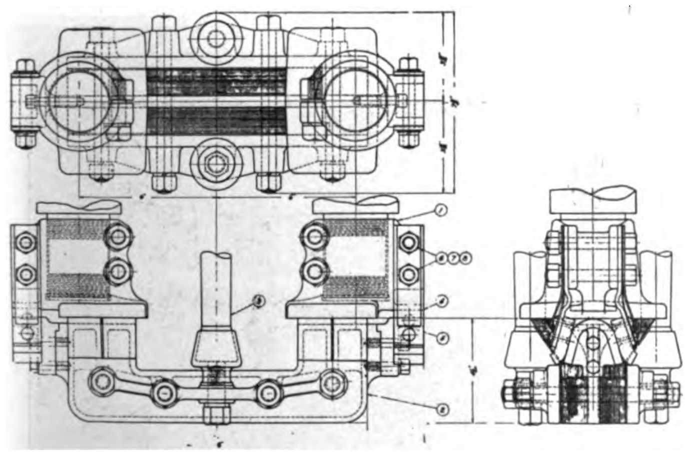
FIG. 2—WESTINGHOUSE ELEC. & MFG. CO. OIL CIRCUIT BREAKER PARTS SHOWING IMPROVEMENTS. (FORMER DESIGN SHOWN IN FIGS. 9, 10, 14 AND 15.)

2A. Quarter elliptic form of inverted brush contact used in the CO-2 1200-ampere, 60-cycle circuit breaker.

2-B. A circular form of inverted brush contact used in the CO-1 1200-ampere, 60-cycle circuit breakers. Considerable attractive force is obtained between the two sides of the brush and the parallel contacts carrying current flowing in the same direction.

2-C. Half elliptic form of inverted brush contact used in the 0-2, 4000-ampere, 60-cycle circuit breakers.

2-D. A new form of contact is to be used in the 0-4, 3000-ampere, 60-cycle circuit breaker. There are no joints in the electrical circuit except at the contact faces and thermal losses are therefore a minimum. On short circuit, the two halves of the brush attract each other due to carrying current in the same direction and are, therefore, pressed more securely against the main contact.



2-D

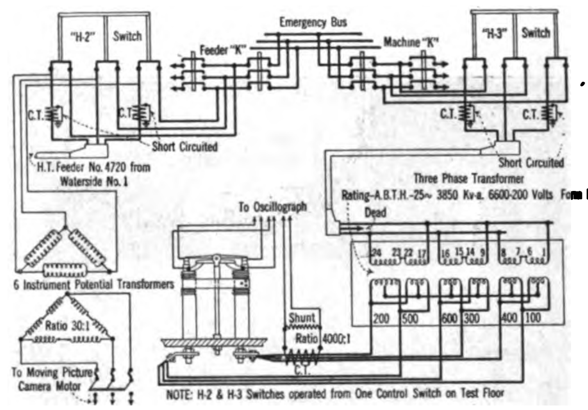


FIG. 3—DIAGRAM OF CONNECTIONS FOR TESTS

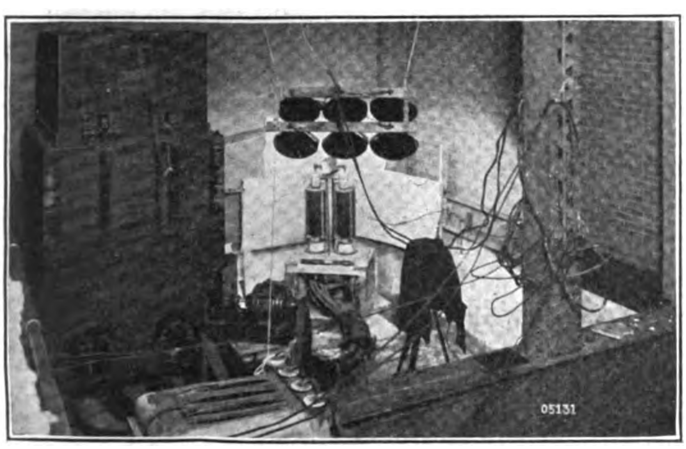


FIG. 4—SET-UP OF APPARATUS FOR TESTS

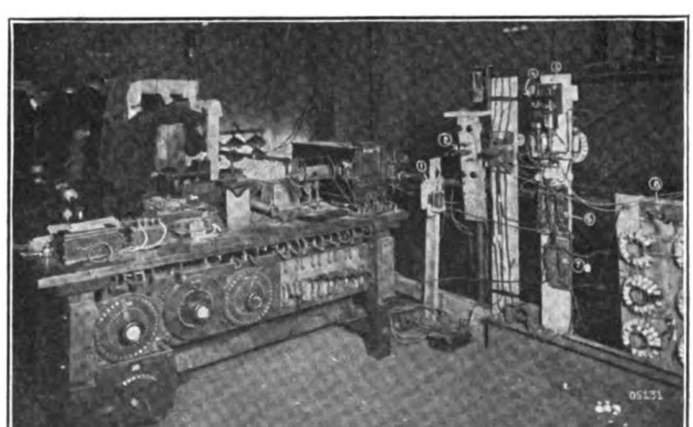


FIG. 5—CONTROL APPARATUS FOR TESTS; MOUNTED ON GALLERY ABOVE THE TEST FLOOR

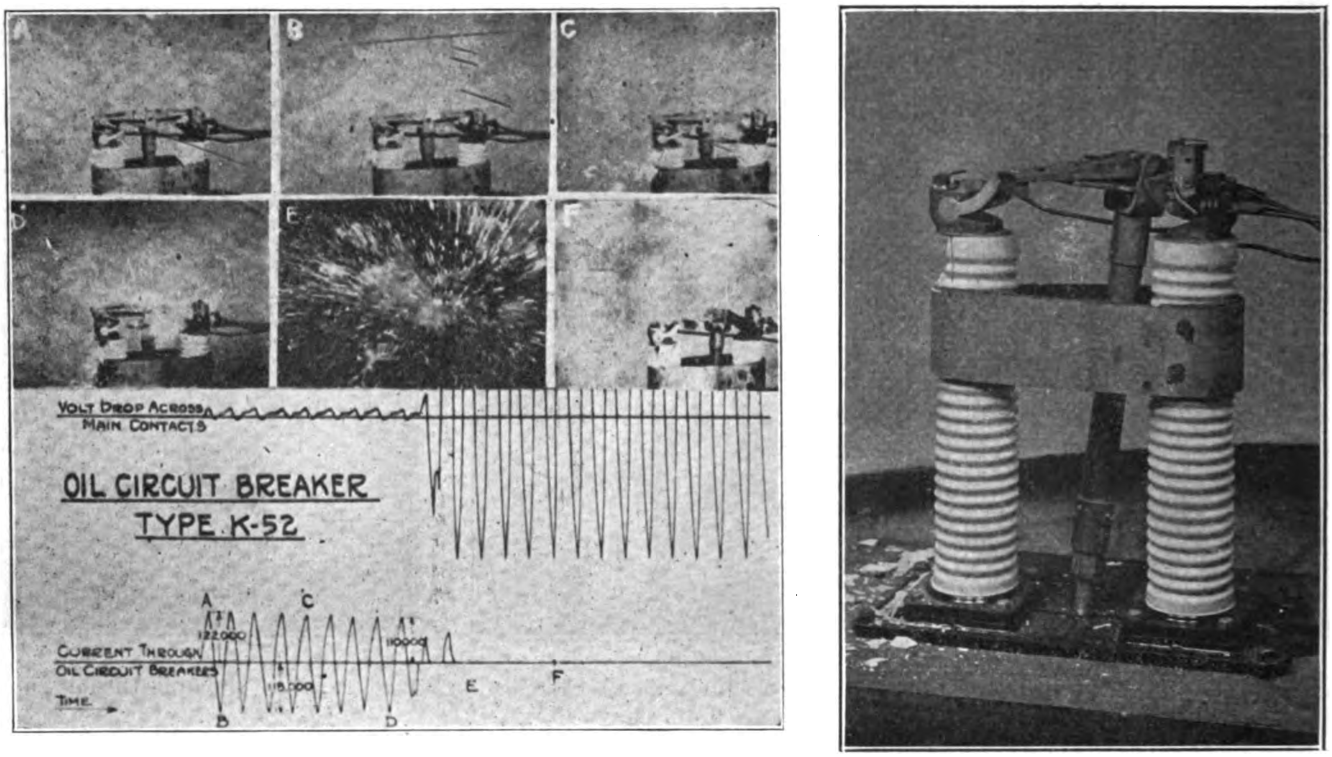


Fig. 6—G. E. Co. K-52 Circuit Breaker Reinforced With Fiber Band

Rating. 125,000 kv-a., 31,500 amperes at 2300 volts.

This circuit breaker was first tested at 27,000 and at 31,000 amperes mean effective which it withstood satisfactorily. It was then given 85,000 amperes mean effective which spread the porcelain pillars, breaking one at the special support, and twisted the movable contact around and entirely off the stationary contacts. Open-circuited at the 9th cycle.

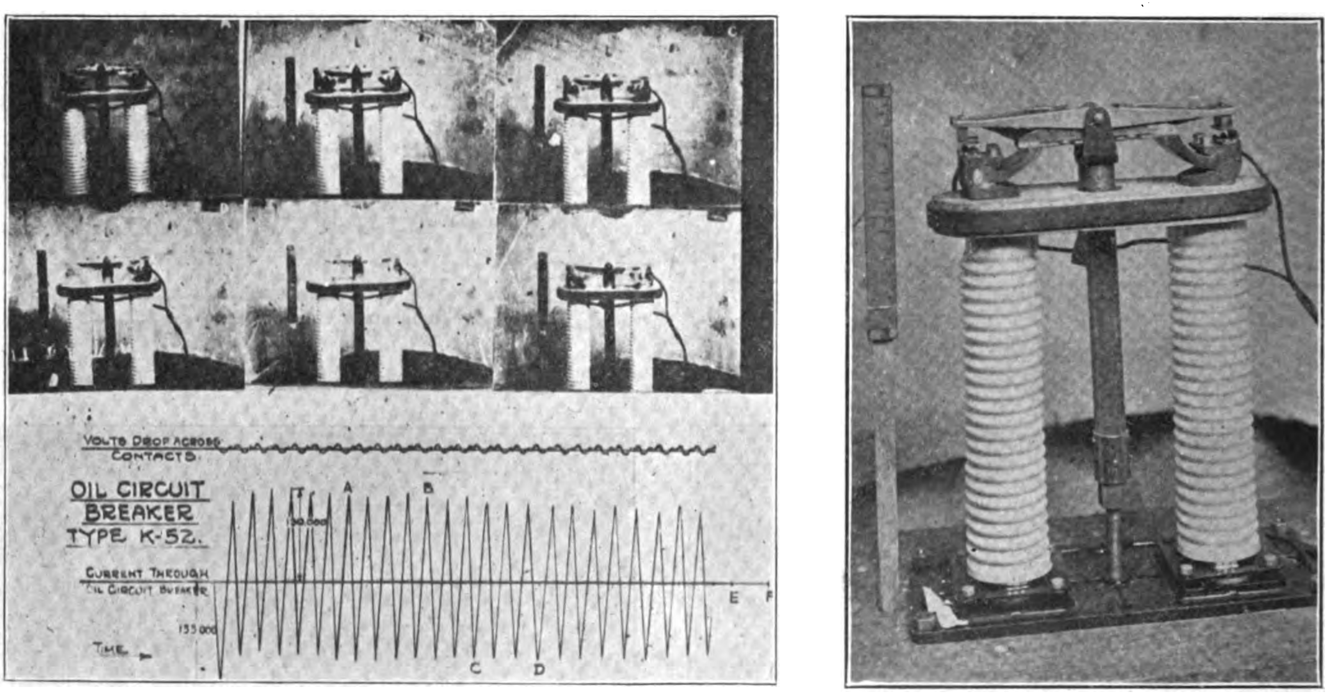


Fig. 7—G. E. Co. K-52 Circuit Breaker Reinforced With Wood and Steel

Rating 125,000 kv-a., 31,500 amperes at 2300 volts.

First withstood a test of 67,000 amperes mean effective. On 98,000 amperes mean effective the porcelain broke at 12th cycle. Slight arcing. Total spread of contacts approximately 3/16 in.

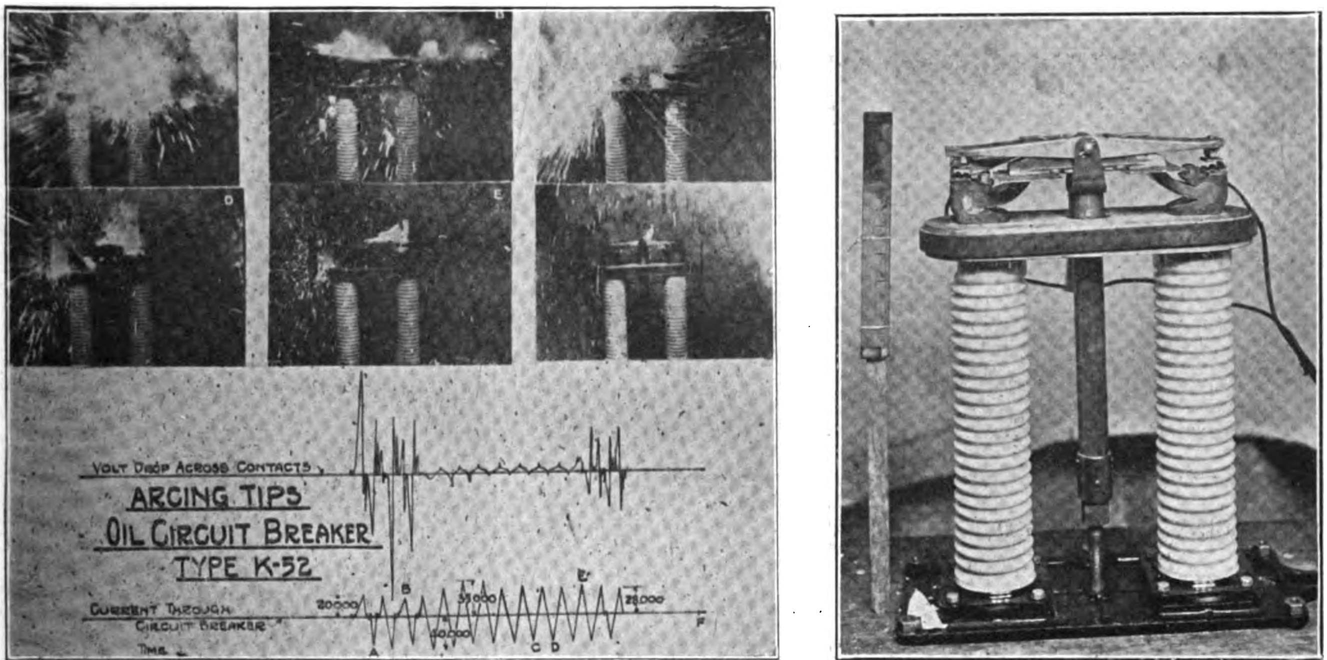


FIG. 8—G. E. CO. K-52 CIRCUIT BREAKER

Test on arcing tips only. Tested at 21,000 amperes mean effective. Contacts lifted on first ½ cycle, and for three consecutive cycles. Remained closed for seven cycles, and again opened for three cycles. Severe burning.

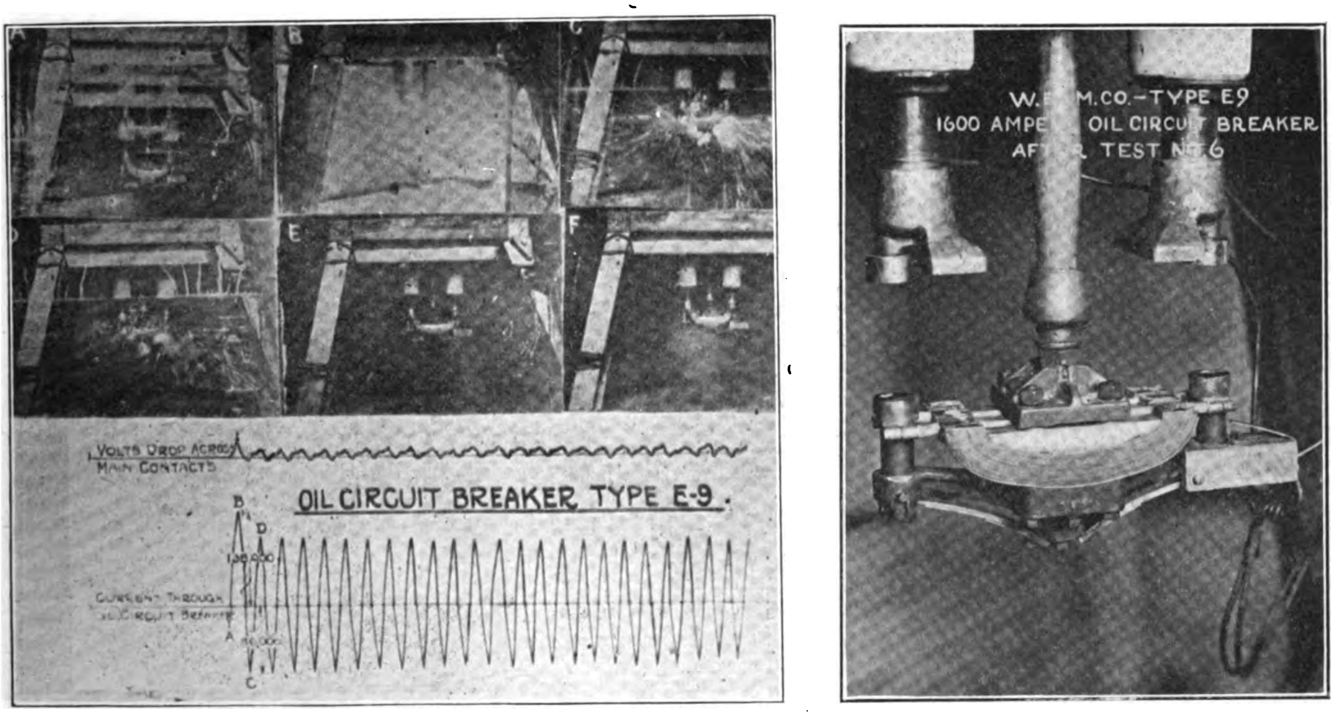


FIG. 9—WESTINGHOUSE E-9 CIRCUIT BREAKER

Rating 160,000 kv-a., 40,000 amperes at 2300 volts.
Tested at 79,000 amperes mean effective. Brushes lifted on first ½ cycle, arced and froze. Total spreading of contacts approximately 5/32 in.

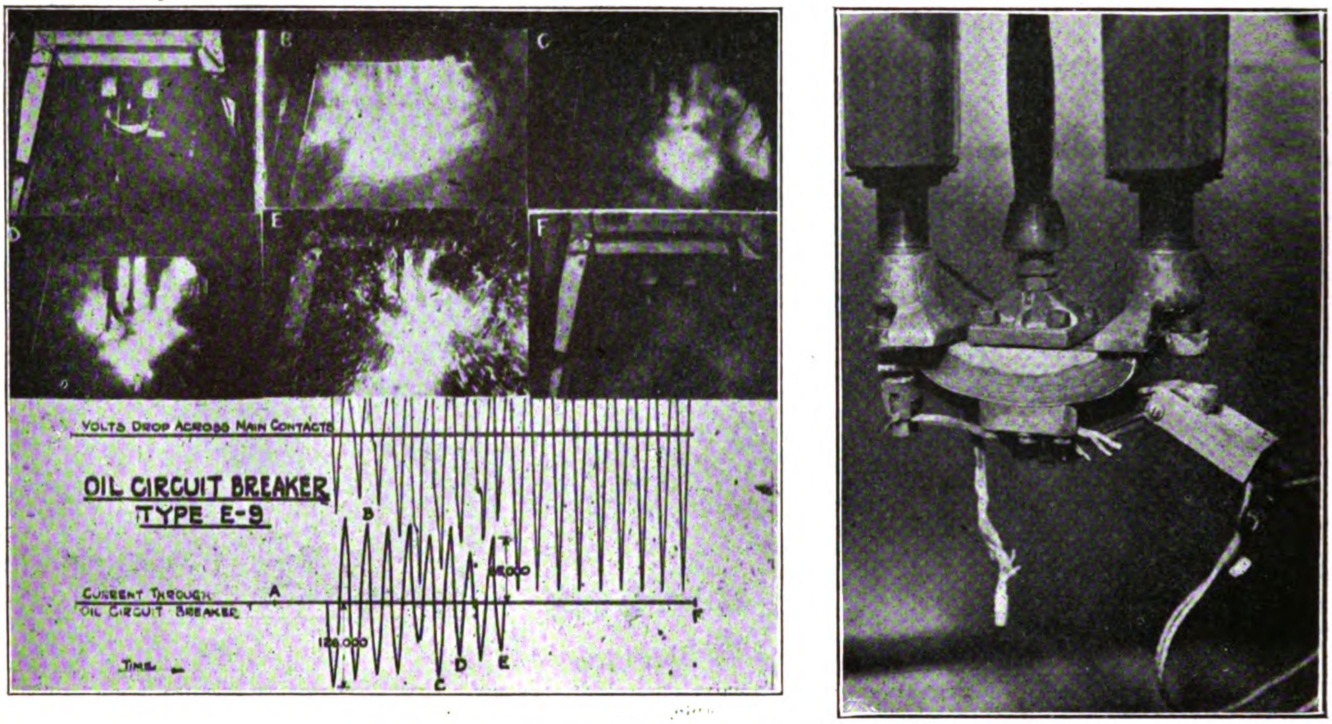


FIG. 10—WESTINGHOUSE E-9 CIRCUIT BREAKER

Rating 160,000 kv-a., 40,000 amperes at 2300 volts.
Tested at 89,000 amperes mean effective. Brushes lifted on first ½ cycle and burned clear at 8½ cycles.

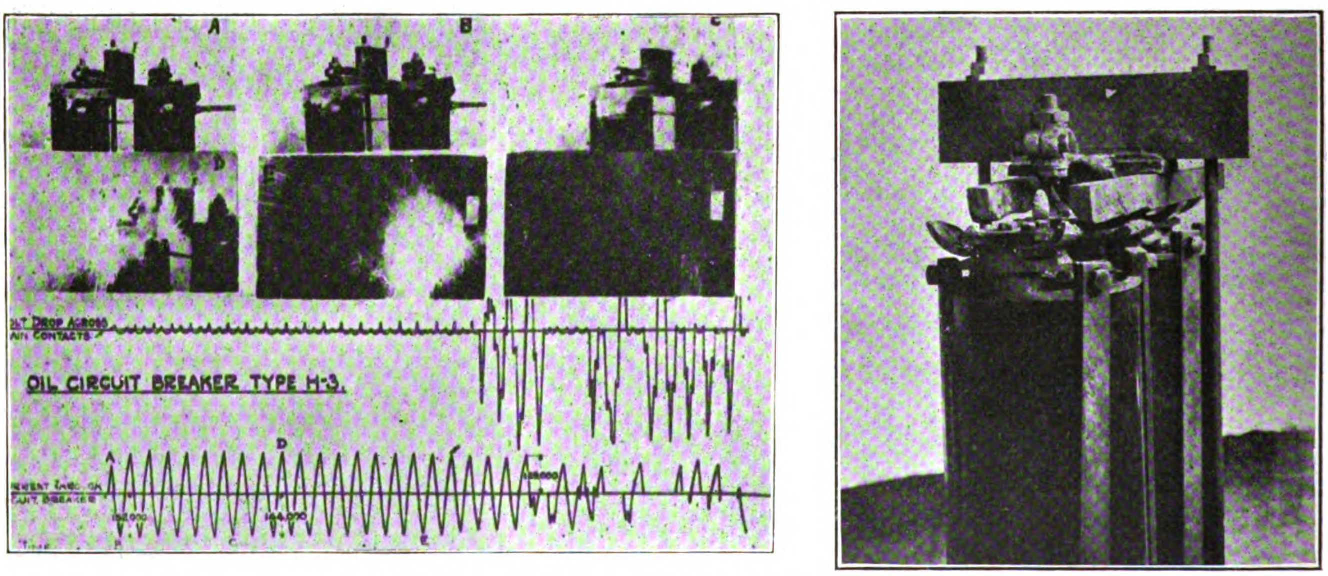
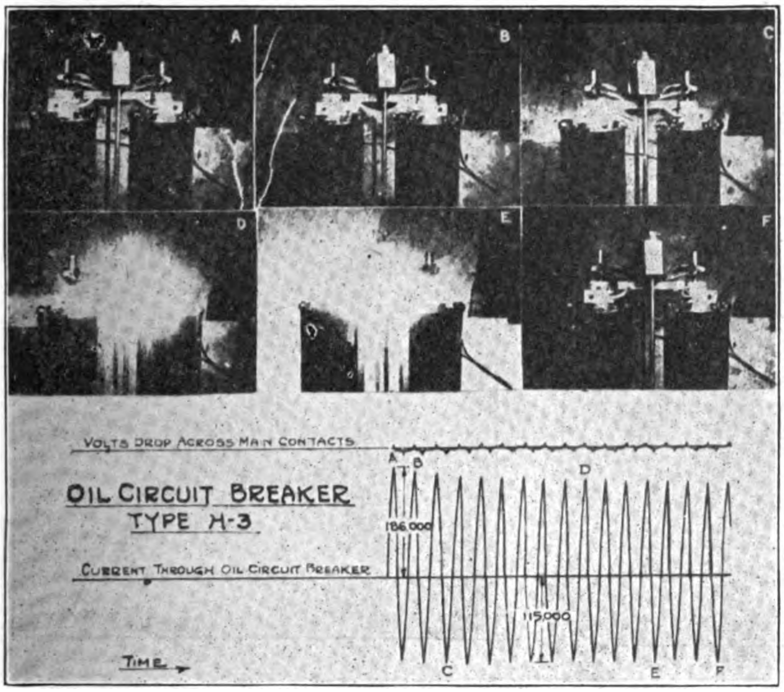


FIG. 11—G. E. CO. H-3 WITH INVERTED BRUSHES

Rating 225,000 kv-a., 63,000 amperes at 2300 volts.
Tested at 103,000 amperes mean effective. Slight arcing at contacts due to vibration and spreading of pots, contact plates collapsed, one of the brass rods burned off, and switch open-circuited.



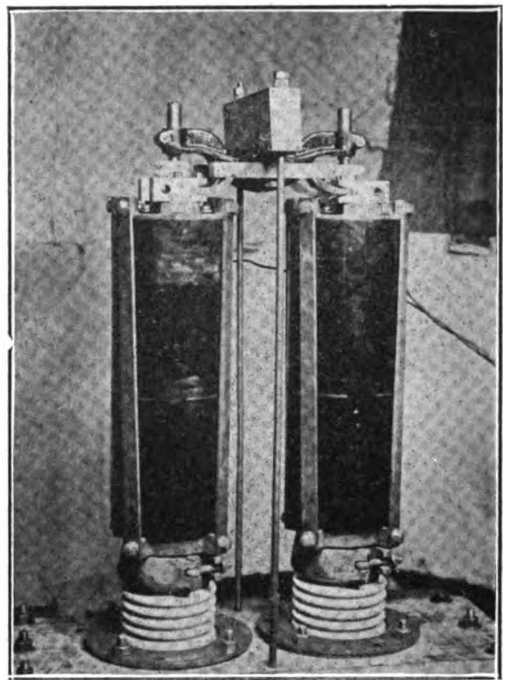
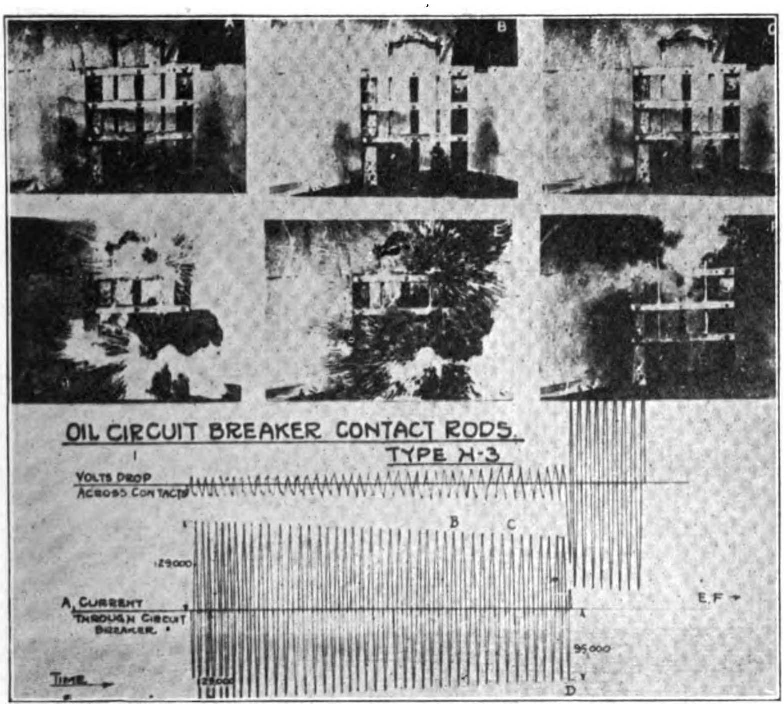


Fig. 12—G. E. Co. H-3 With Trial Brushes

Rating 225,000 kv-a., 63,000 amperes at 2300 volts.

Tested at 112,000 amperes mean effective. Slight arcing at contacts due to vibration. One brass rod was bent. Total spreading of pots 1 1/8 in. The bright irregular lines at the left edge of Section B of the film are caused by static discharge due to the high speed at which the films were taken This appears in a number of the motion pictures, notably Section E of the film in Fig. 17.



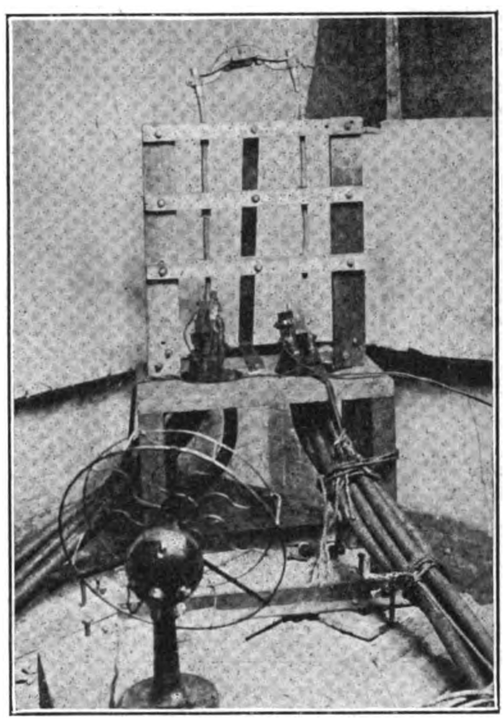


Fig. 13—G. E. Co. H-3 Contact Rods

Standard brass rods tested at 41,000 amperes mean effective, burned off at contact with crossarm in 0.57 sec. Copper rods tested at 91,000 amperes mean effective, burned off in body of rod in 1.8 sec. Copper rod test shown above. Note bending between supports.

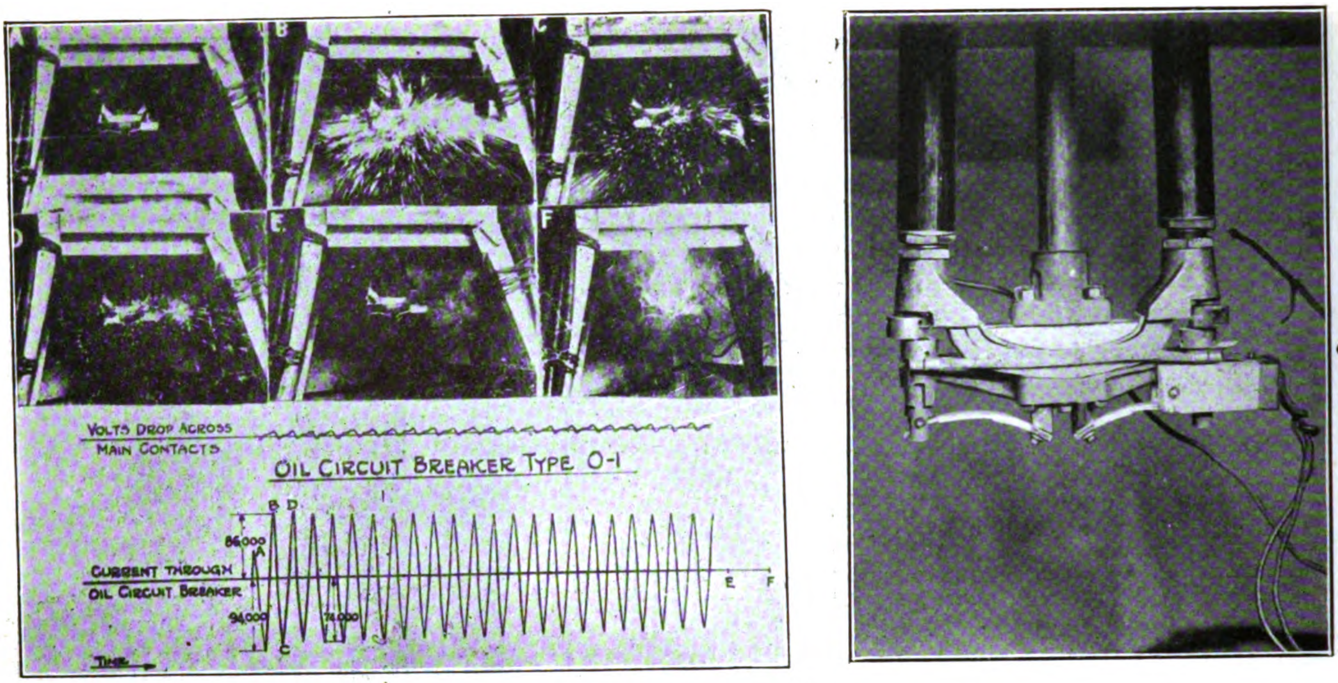


FIG. 14—WESTINGHOUSE O-1 CIRCUIT BREAKER

Rating 350,000 kv-a., 88,000 amperes at 2300 volts.

Tested at 63,000 amperes mean effective. Brushes lifted on first ½ cycle, froze and remained closed. Total spreading of supports approximately 3/16 in.

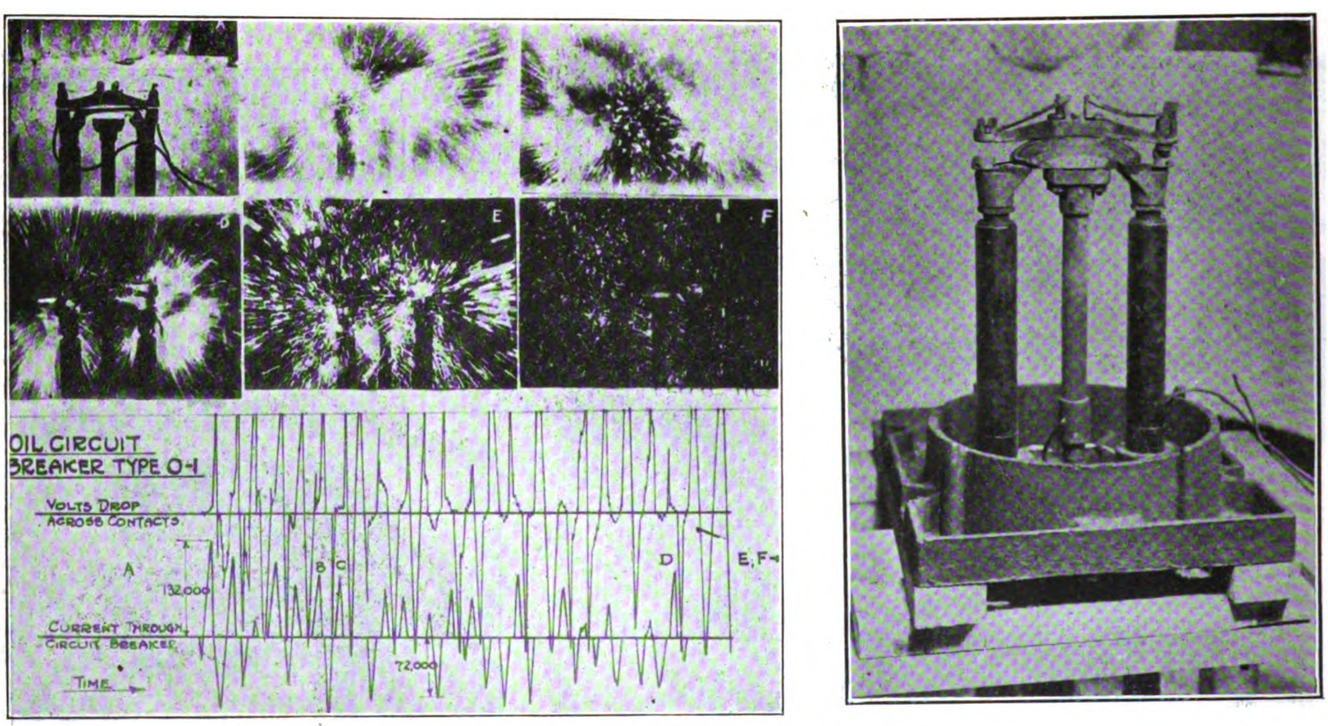
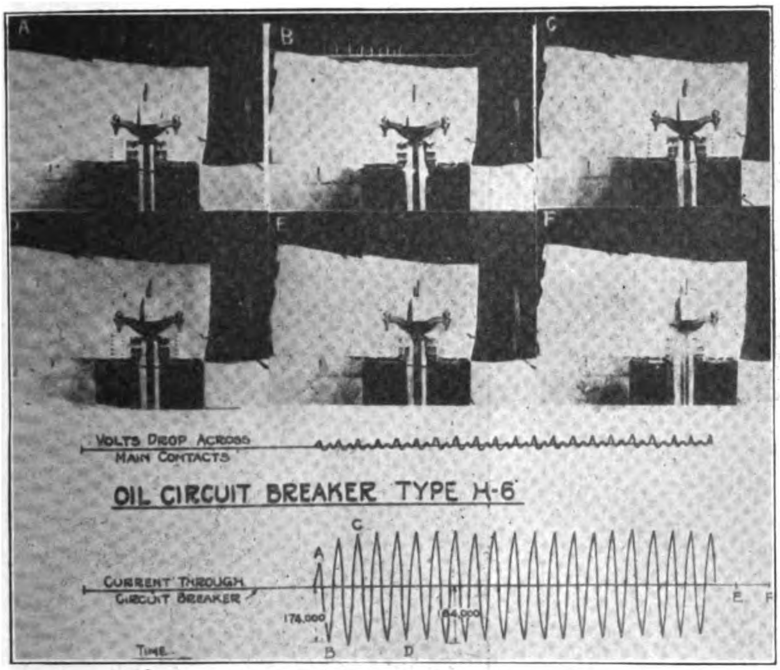


FIG. 15—WESTINGHOUSE O-1 CIRCUIT BREAKER

Rated at 350,000 kv-a., 88,000 amperes at 2300 volts.

Tested at 84,000 amperes mean effective. Brushes lifted on first ½ cycle and continued intermittently throughout test. Arcing tip destroyed. Considerable spreading of supports during test but no permanent spreading noticed.



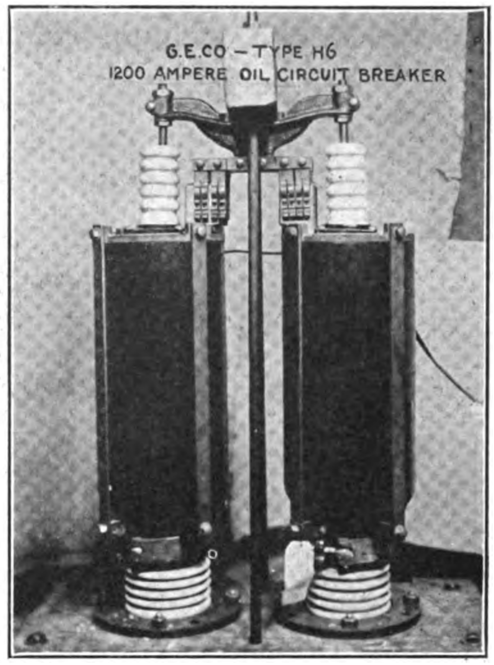
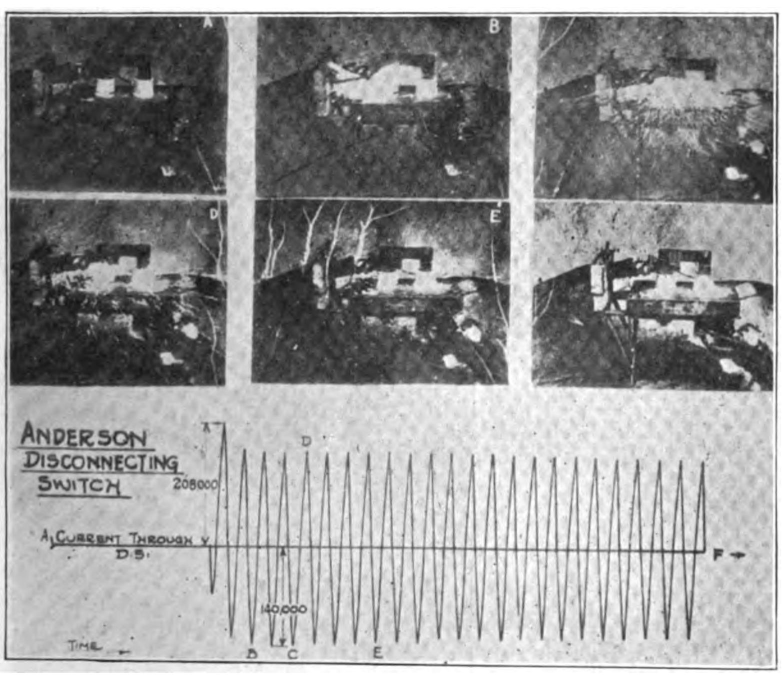


FIG. 16—G. E. CO. H-6 CIRCUIT BREAKER

Rated at 350,000 kv-a., 88,000 amperes at 2300 volts.

Tested at 130,000 amperes mean effective. Pots spread at first ½ cycle, no arcing. Parallel paths through moving contact causes attraction of contact fingers and, therefore, tightening instead of opening of contacts. Total spreading of pots approximately one in.



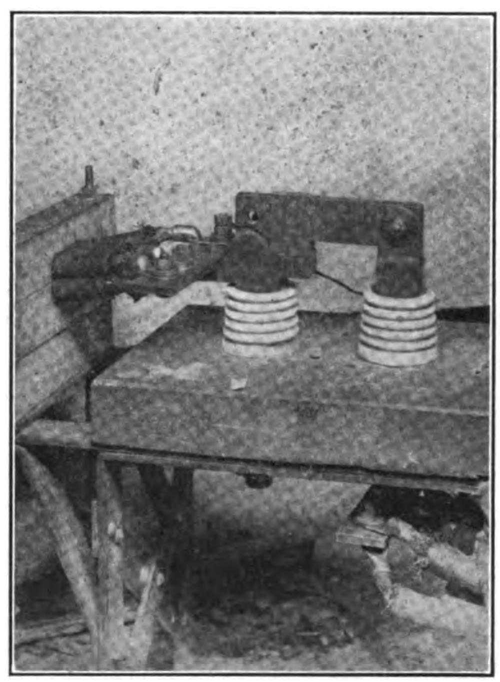
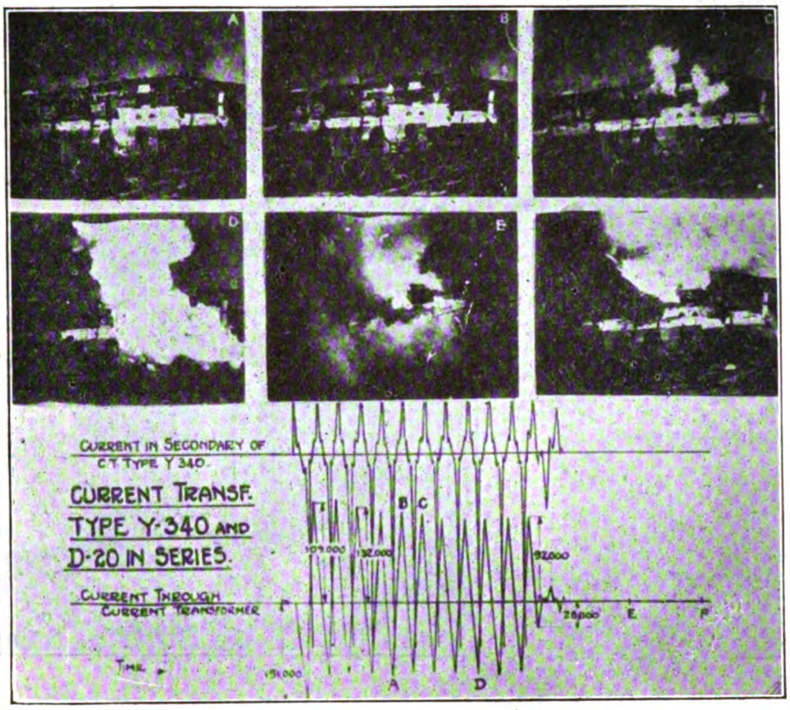
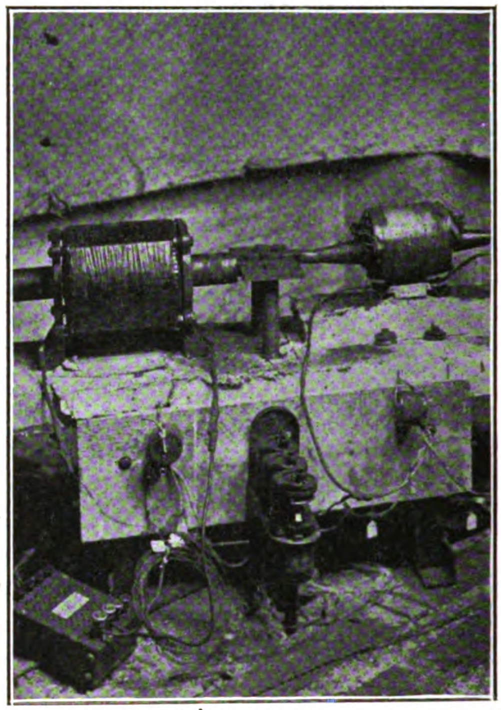


FIG. 17—ANDERSON DISCONNECTING SWITCH WITH SPECIAL LOCK

Tested at 130,000 amperes mean effective. Slight chipping of porcelain. No damage to switch. Arcing shown was due to poor contact at terminal.

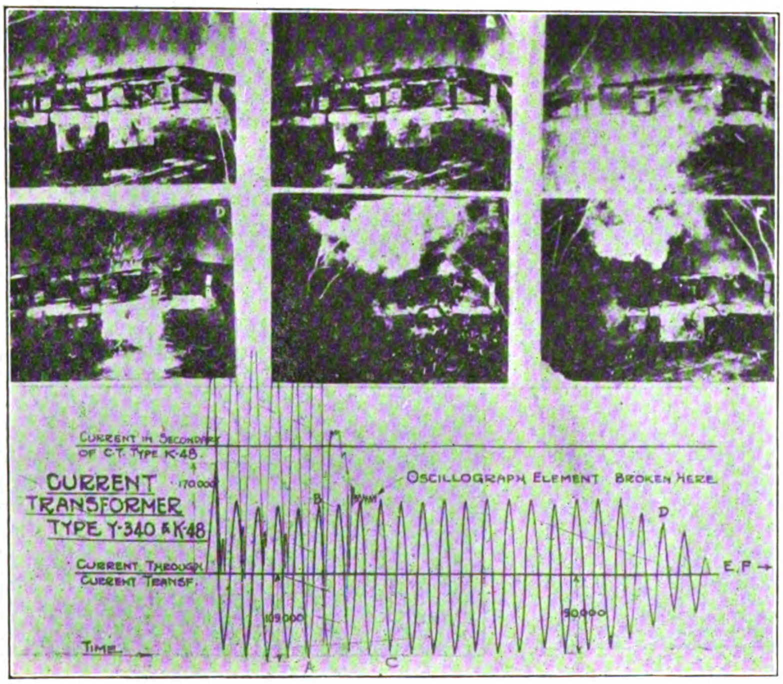


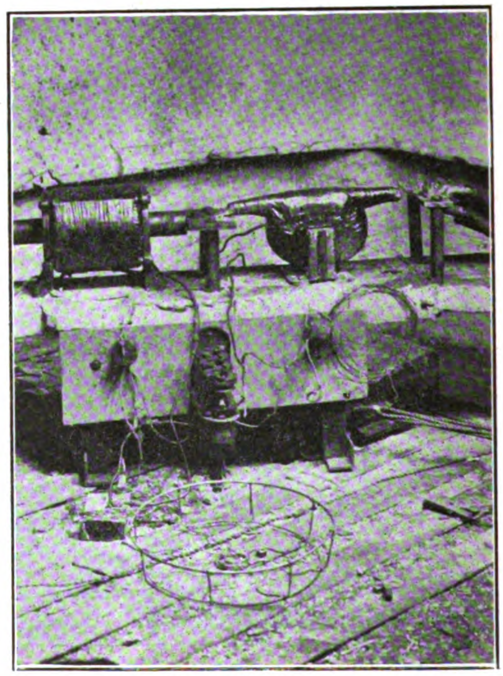


After test

Fig. 18—G. E. Co. Current Transformer Y-340 and D-20, Single-Turn.

Tested at 92,000 amperes mean effective. Primary of D-20 blew open after 12½ cycles. Secondary destroyed. Y-340 not injured. (D-20 is a superseded type).





After Test

Fig. 19—G. E. Co. Current Transformers. Y-340 and K-48 Single-Turn.

Tested at 101,000 amperes mean effective. Primary of K-48 opened after 23½ cycles, due to failure at terminal. Y-340 not injured.

the mechanical force resulting from the high current. This phenomenon occurs in practise before the operating mechanism has had sufficient time to perform its function in opening under short circuit.

On the basis of the results obtained, the manufacturers have revised the design of their circuit breakers so as to eliminate the trouble due to contact separation and displacements, as shown in Fig. 1 for General Electric Company apparatus, and in Fig. 2 for Westinghouse Company apparatus. Other detail improvements are referred to in the illustrations hereinafter given.

Testing Equipment

Current for the tests was supplied by two 10,000-kw. generators in Waterside station, operated in parallel

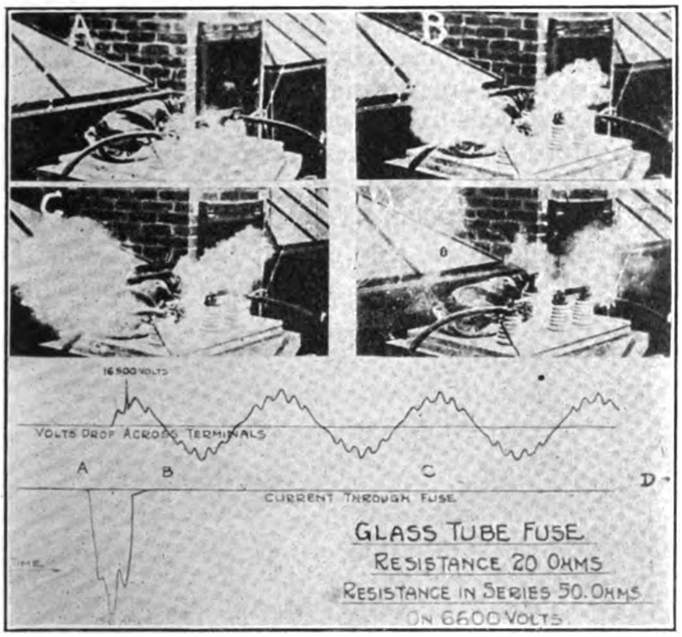


Fig. 20—Glass Tube Fuse of 20 Ohms Resistance With 50 Additional Ohms in Series.

Tested at 6600 volts. Mean effective 156 *amperes maximum*. Tube was unbroken but asbestos filler was expelled from both ends. Duration of current 0.27 cycle. Circuit opened successfully.

and connected through their reactors to an emergency bus. This bus was connected, through the tie bus reactors, to a second emergency bus to which a 350,000-cir. mil feeder was connected for supplying power for the tests at the West 41st Street substation. (See Fig. 3.)

At the substation, the feeder *H*-2 and the *H*-3 switch of a 3500-kw. synchronous converter were connected in series through their *K* switch and the emergency bus to the high-tension side of a 3850-kv-a., three-phase synchronous converter air-blast transformer. The control circuit of the two *H* switches was connected to operate from the control switch as a four-break unit. The three high-tension transformer windings were connected in multiple as a single-phase transformer. The six low-tension windings were similarly connected, giving 170 to 200 volts at full voltage.

The records of the test were made by oscillograph, and a motion picture camera was driven synchronously from the feeder supplying energy for the tests; also

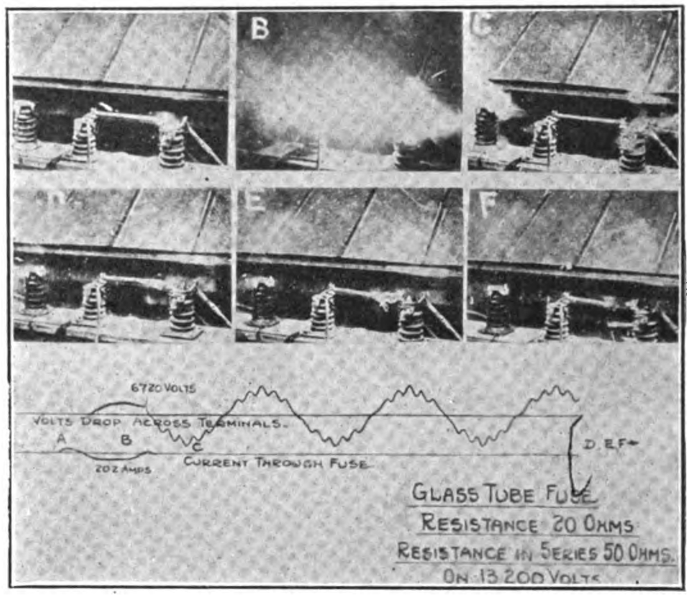


Fig. 21—Glass Tube Fuse of 20 Ohms Resistance With 50 Additional Ohms in Series

Tested at 13,000 volts mean effective, 202 *amperes maximum*. Fuse exploded. Caps remained in clips. Duration of current 0.58 cycle. Fuse opened circuit.

a Lichtenberg high-speed camera was used. In addition, close-up pictures were made of each subject with the ordinary camera after each test.

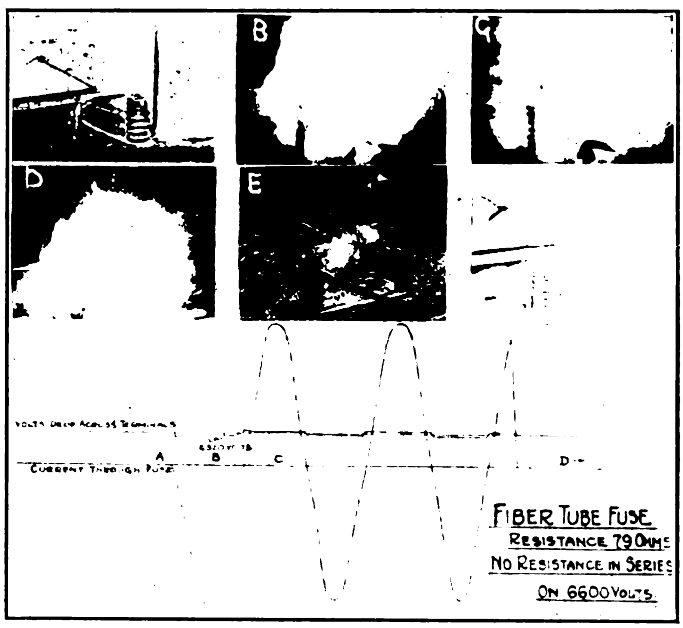


Fig. 22—Fiber Tube Fuse of 79 Ohms Resistance With no Additional Resistance in Series

Tested at 6600 volts mean effective 1970 *amperes maximum*. Fuse completely blown to pieces. Circuit opened manually. Duration of current 3.1 cycles.

The oscillograph had three vibrators, one of which was used to measure the secondary current in the type *E*-3 General Electric Company current transformer,

20,000-ampere, 4000 to 1 ratio. The second vibrator was used to measure the voltage drop across the brush contacts. The third vibrator was used to give a 25-cycle timing wave from the Waterside main bus, ex-

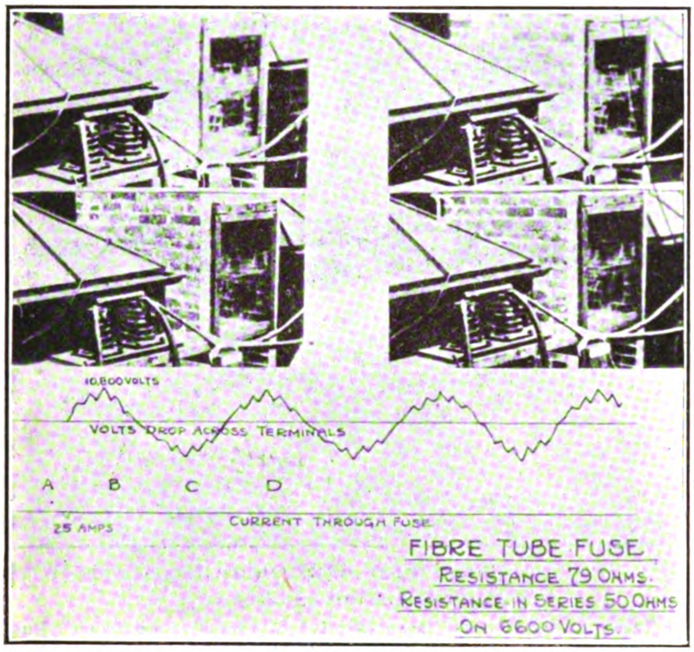


FIG. 23—FIBER TUBE FUSE OF 79 OHMS RESISTANCE WITH 50 OHMS ADDITIONAL IN SERIES

Tested at 6600 volts mean effective, 25 *amperes maximum*. Fuse opened the circuit without visible disturbance. Duration of current 0.02 cycle.

cepting in tests of circuit breakers having auxiliary arcing tips. On circuit breakers so equipped the third vibrator was connected to give an alternating wave only when the auxiliary contact was lifted 1/32 inch or more. For some of the tests, the third vibrator was connected to measure the current on the primary side of the testing transformer. The oscillograph was calibrated immediately before and after the tests.

The motion pictures were made by a standard Moye camera, gear-driven, from a ½-h. p. synchronous motor. The calibration was accomplished by photographing an ordinary arc lamp operating on 25 cycles from the same source which drove the motor, and adjusting the shutter so that the full opening occurred at the point of greatest brilliancy in the arc.

The camera was started and brought to synchronous speed before the test current was applied to the subject. The camera operation was continued synchronously until after the test current was interrupted. Two pictures were taken during each cycle, adjacent pictures therefore, showing events at a time interval corresponding to 180 electrical degrees, or one-fiftieth of one second. The camera shutter design was such that the exposure for each picture lasted during about 60 electrical degrees. Figs. 4 and 5 show the apparatus.

The Lichtenberg camera was equipped with a lens board and 24 lenses arranged to give successive exposures. It was set to take its 24 pictures during the first two cycles of the test current. As the tests progressed, however, the time of exposure was increased somewhat to obtain better negatives. Although these pictures were, in general, a success, they are not shown herein, as the motion pictures, being in synchronism with the oscillograph records, more adequately illustrate the results obtained.

RESULTS OF TESTS

From all the records, in Figs. 6 to 16 inclusive, are combined characteristic results of motion pictures and oscillographs for the apparatus tested.

DISCONNECTING SWITCHES

The same mechanical stresses caused by flow of high currents, as reviewed in the paragraph on oil circuit breakers, apply, to a large extent, to the design of disconnecting switches. The ideal installation would be a straight disconnecting switch in series with the main circuit without bends. When, however, bends are necessary, the blade opening should be at right angle to the main lead. In addition, suitable strong locking devices are to be provided. See Fig. 17.

CURRENT TRANSFORMERS

In large systems, only current transformers of the single-turn, primary type are capable of withstanding

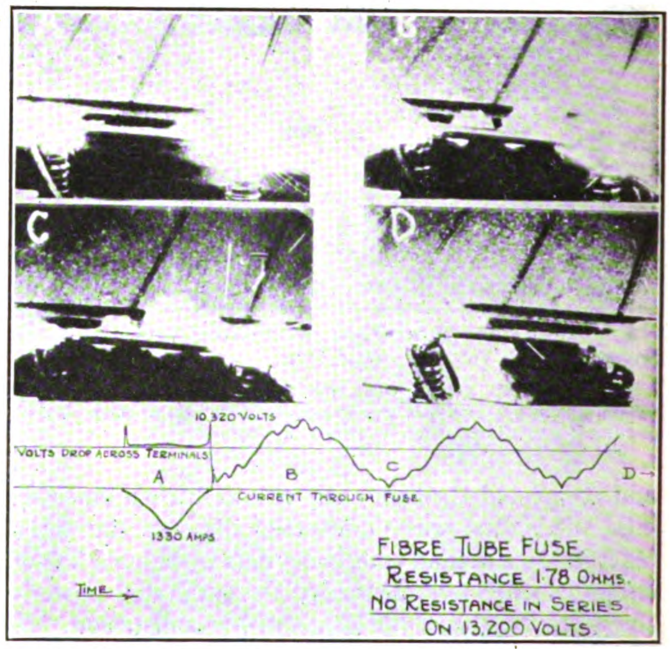


FIG. 24—FIBER TUBE FUSE OF 1.78 OHMS RESISTANCE WITH NO ADDITIONAL RESISTANCE IN SERIES

Tested at 13,000 volts mean effective, 1330 *amperes maximum*. Fuse blew out end of caps but opened the circuit. Duration of current 0.54 cycle.

short circuits as may occur on the system. The other current transformers are too weak, and will be either ruptured mechanically or destroyed thermally. See Figs. 18 and 19.

POTENTIAL TRANSFORMER FUSES

Extensive tests were made with and without resistance in series. The tests have conclusively proved

that no type of potential fuse on the market can satisfactorily open the circuit without a resistance in series. The company first used a resistance wire wound spirally on a rope core and insulated suitably for the voltage on which it was applied.

Recently, the suggestion has been made to use an asbestos card with a resistance wire wound on it in series with the fuse. Where space does not permit the use of the high-resistance lead, this substitute may be of advantage. See Figs. 20 to 24, inclusive.

The Maximum Safe Operating Temperature of Low-Voltage Paper-Insulated Cables

BY W. A. DEL MAR
Chief Engineer, Habirshaw Electric Cable Co.

The Standards of the Institute state that for low-voltage cables the maximum safe operating temperature is 85 deg. cent. Experiments show that continuous operation at 100 deg. cent. for less than a month, seriously impairs the mechanical condition of impregnated paper. A standard of permissible mechanical condition should, therefore, be established, if such high temperatures are to be allowed. Operation at higher temperatures than allowed by the present Standards is, however, in the nature of a gamble and it is questionable whether the Standards should take cognizance of it.

Statement of the Problem

NOTHING would seem more simple than to determine the maximum safe operating temperature of an insulating material such as impregnated paper; but the problem is really very complicated as several preliminary problems of an important character must be settled before the main problem can be adequately attacked. These preliminary problems are as follows:

1. What is the criterion of quality of paper insulation by which we may say whether it is satisfactory for service?
2. What is the effect of the continued application of various degrees of heat, expressed in terms of the criterion selected?
3. Will intermittent heat have the same effect as continuous heat provided the aggregate time of exposure and the temperature are the same in both cases?
4. If the above questions should be satisfactorily answered, what form of rule should be adopted so as to make the best economic use of the information thus obtained?
5. If a rational rule for the maximum permissible temperature of paper insulation should be developed, how can the hottest-spot temperature of a cable in a duct be measured in order to ensure that the cable is working within the rule?

These questions cannot all be answered at the present time, and the object of this group of papers is to gather together such data as are available in order that the Standards Committee of the Institute may be able to revise its present rule for the temperature limits of paper insulation in the light of the best information which the members of the Institute can furnish.

To be presented at the 9th Midwinter Convention of the A.I. E. E., February 16-18, 1921.

Criterion of Quality

In the case of low-voltage cables, which are the only ones under present consideration, the criterion of quality by which we may judge whether the cable is usable, should be the mechanical strength, because it is that quality which determines whether the cable can withstand handling, expansion and contraction, and possible reinstallation. New cables of the best quality have but little margin of strength to take care of the stresses imposed on the insulation during installation. Large cables are often installed in splicing chambers originally designed for small cables, and are consequently bent on curves of dangerously small radius, and are subjected to very rough handling. Even where splicing chambers are adequately designed, the cables are often handled with entire disregard of their mechanical limitations. However, once the cables are installed, they are free from mechanical stresses except such as may result from expansion and contraction due to variations of temperature. A different criterion of quality may therefore conceivably be adopted for cables after they are installed from that for new cables, but the use of such a standard would preclude the possibility of reinstalling cables which have deteriorated to that standard.

Some cable specifications contain clauses requiring the paper to have a certain minimum tensile strength, but tensile strength tests are unsatisfactory because the paper may become brittle, and may tear easily, while the tensile strength remains quite high.

Bursting strength tests, as made on a Mullen tester, are unsatisfactory for the same reason. A test, which proved to be really satisfactory, is the tearing test. A piece of paper about three centimeters wide is carefully cut with a razor along its center line from one end to about its center, and a pencil mark made one centimeter beyond, as shown in Fig. 1. It is then suspended

from one of the small ends as shown in Fig. 2, and a balance pan attached to the small free end, the large end being allowed to swing free. Sand is then poured continuously into the pan until the paper begins to tear. The stream of sand is then continued slowly, stopping if the paper continues to tear, but proceeding if the tearing stops. It is continued until the tear reaches the centimeter mark. The total weight of pan and sand expressed in grams is taken as the tearing strength of the paper. The reason for letting the paper tear a definite amount, rather than to observe the weight at which the paper begins to tear, is that paper varies in thickness and condition from place to place, and the initial tear would only represent the strength at a spot and would not be a measure of the average

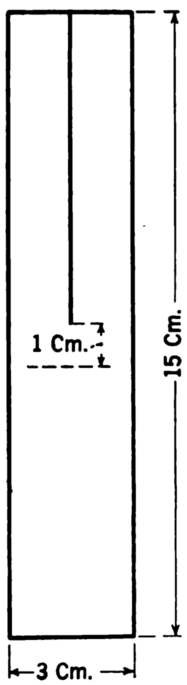


FIG. 1—SAMPLE FOR TEARING TEST

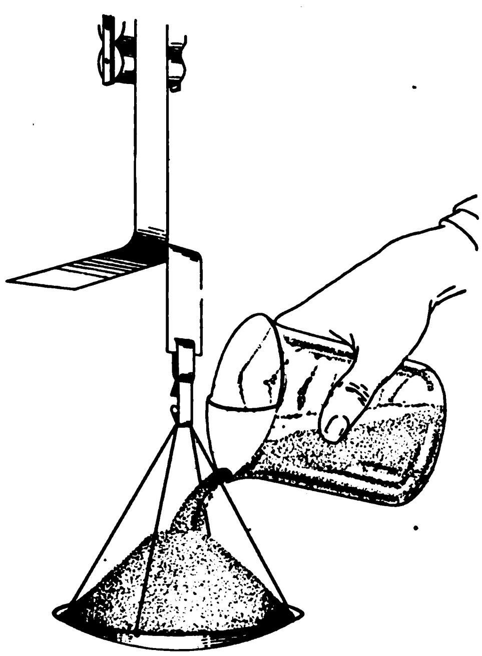


FIG. 2—TEARING TEST

quality. The tearing strength of unimpregnated Manila rope paper 0.02 mm. (8 mils) thick, under ordinary conditions is from 170 to 285 grams (6 to 10 oz.) When impregnated, the tearing strength is usually less than this, depending upon the nature of the impregnating compound, the temperature and duration of the process of impregnation and the amount of the compound retained upon cooling. Manila rope paper usually contains from 5 to 10 per cent of moisture. Tests were made to ascertain whether the percentage of moisture had any effect upon the tearing strength. The results are shown in Fig. 3, which shows that an increase of moisture increases the tearing strength up to a certain point and decreases it above that point. Statements of tearing strength are, therefore, not complete unless the moisture content is specified.

Tests to ascertain the effect of the continued application of various degrees of heat may be made either with samples of finished cable or with samples of paper immersed in compound. A preliminary test was made to ascertain whether these two kinds of tests give the same results. It would be difficult to make direct observations to prove this point owing to the impossibility of being sure that the cable and the separate samples of paper were both subjected to the same heat and mechanical treatment prior to the test. Resort was therefore had to an indirect test. A beaker of hot

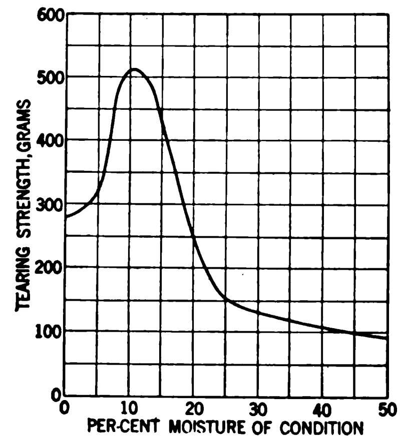


FIG. 3—EFFECT OF MOISTURE ON TEARING STRENGTH OF UNIMPREGNATED PAPER

petrolatum compound was dried in vacuo at 135 deg. cent. until all the volatile matter was driven off, and was then exposed to air at the same temperature for three hours. It was found that no increase in weight occurred, indicating that there was no oxidation. If the paper is wound in rolls similar to cable insulation and immersed in beakers of impregnating compound, the actual conditions in a cable should be closely simulated.

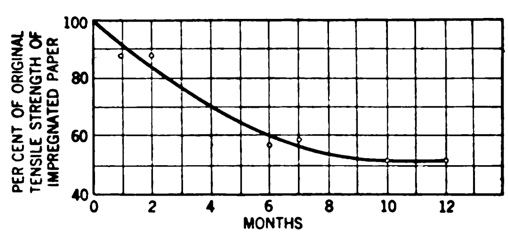


FIG. 4—LOSS OF TENSILE STRENGTH OF IMPREGNATED PAPER IN PETROLATUM-RESIN COMPOUND AT 85-90 DEG. CENT.

EFFECT OF CONTINUOUS HEATING

Tests were made upon rolls of paper immersed in open beakers of petrolatum-resin compound maintained between 85 and 90 deg. cent. for a year. These tests were made before the development of the tearing test and the results are therefore expressed in terms of tensile strength. The gradual loss of strength is shown in Fig. 4, which shows that at the end of a year, the paper had lost about half the tensile strength it possessed just after impregnation. It is probable, that the tearing strength would have been even more reduced. The paper, however, was in quite good enough condition at the end of a year for new low-voltage cables.

Tests were made upon unimpregnated paper with the object of determining the behavior of Manila rope paper exposed to high temperatures. Samples of paper were heated in vacuo successively at 70 deg., 80 deg., 90 deg., 100 deg., 110 deg., 120 deg., 130 deg., 140 deg., 150 deg., and 160 deg. cent., the temperature of all samples being maintained at each of these points for as many periods of one hour as were required to ensure that constant weight was obtained. The average results are shown in Fig. 5 which indicates that the loss in weight increases slowly up to about 120 deg. cent., but then rises rapidly. At 130 deg. cent. oily globules distil off; at 140 deg. cent. the paper darkens, indicating charring. The loss of weight which occurs above 120 deg. cent. is not necessarily due to loss of moisture. However, some of the material which distills off is undoubtedly moisture, but this may be due to the decomposition of the cellulose, which is a carbohydrate having a composition of $(C_6H_{10}O_5)_x$, which may, therefore, be reasonably expected to yield water among its products of decomposition.

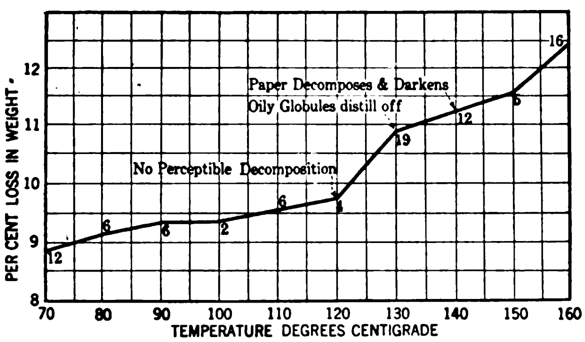


Fig. 5—Unimpregnated Paper

The figures at each point of the curve represent the number of hours of heating at each temperature before proceeding to the next. A steady weight was reached in about one hour less than these periods.

Another series of tests was made by putting a roll of dried paper in a beaker of petrolatum-resin compound for three hours and noting the loss in tearing strength. This test was made on a separate roll for each of six temperatures from 70 to 140 deg. cent. The results are shown in Fig. 6 and indicate the degree that impregnated paper may be injured by three hours exposure to the temperatures covered by these tests. As in the year test at 85-90 deg. cent. the paper in any of these rolls was in good enough condition for new low-voltage cables.

The most decisive series of tests was made on sealed lead-sheathed cables placed in an electric oven maintained carefully at a temperature of 100 deg. cent. The temperature was measured by three thermometers, one above, one below the samples, and one fastened to a cable sheath under a felt pad. The reading of the upper thermometer was about 99 deg. cent. and the under thermometer about 101 deg. cent. The thermometer on the cable sheath read a fraction of a degree below the mean air temperature in the oven. The mean temperature was kept constant by a calibrated thermostat, the maximum variation being 1½ degrees above or below the mean. At the end of a week, one sample of cable was removed and its paper tested for tearing strength and tensile strength. About 6 pieces of paper were taken for each test, and the results being substantially uniform, a mean was taken for the tearing strength and one for the tensile strength. This test was repeated at the end of 2, 3 and 4 weeks. After the fourth week, the paper had

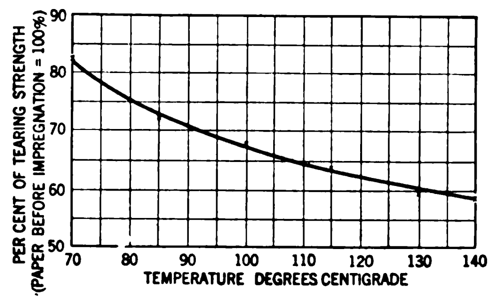


Fig. 6—Effect of Heating Paper in a Beaker of Petrolatum-Resin Compound for Three Hours

A special sample was used for each point.

become so brittle that it cracked apart when folded. The results of the test are shown in Fig. 7, and they indicate that the mechanical strength of paper insulated cables is destroyed by *continuous* exposure to a temperature of 100 deg. cent. for three or four weeks.

As the insulation was intact before the samples were opened at the end of a month, and as they were thoroughly dry, the electrical properties of the cable were undoubtedly quite good enough for low-voltage operation, provided it was not disturbed.

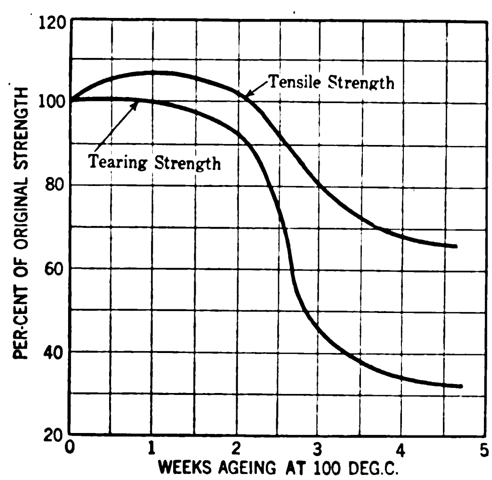


Fig. 7

Distribution systems may therefore be in satisfactory operation with cables in the condition of these samples, but the risk of operating them in this condition is obviously greater than with the insulation in good mechanical condition.

Intermittent Operation

A test to give the same aggregate exposure to heat as in the test described above would last 8 months

if the cable were heated for 3 hours every day. Such a test is under way, but the results will not be available in time for the Convention. If intermittent heat has any less effect than continuous heat of the same aggregate duration, it must be because paper recovers some of its strength during the low-temperature portions of the heat cycle. Tests on numerous samples of heat-injured paper failed to show such recovery.

Form of Rule for Maximum Temperature

The present Standards of the American Institute of Electrical Engineers give 85 deg. cent. as the maximum permissible temperature of impregnated paper insulation for low-voltage cables. The following table shows the increase in carrying capacity that would result from operation at higher temperatures, assuming 40 deg. cent. duct temperature.

Ultimate temperature deg. cent.	Increase of carrying capacity over that for 85 deg. cent. ultimate temperature, per cent.
85	0
90	5
95	9
100	13
105	17

This increase of carrying capacity may sometimes warrant the use of cables at destructive temperatures, and the operating engineers may rightly consider such a procedure to be entirely justified. It is questionable, however, whether the Institute should make a rule to cover such cases, as an Institute rule necessarily represents an agreement between manufacturer and user and it is unreasonable to expect the manufacturer to share the risks resulting from operation at or beyond the limit of endurance of his product.

Use of a Rule for Maximum Temperature

Assuming all of the above problems to be satisfactorily answered, we would still be confronted by the difficulty of applying our knowledge to practical operating conditions, because it is almost impossible to ascertain accurately the hottest-spot temperature of a cable in a duct. This problem is complicated by the presence of other cables in neighboring ducts and by the variable thermal resistivity of the soil. The Cable Research Committee of the National Electric Light Association is giving serious attention to this problem.

The present interest in this subject arises from the increased loads which war conditions suddenly imposed on the central stations and the consequent enforced operation of cables at higher temperatures than were previously thought safe. The experience of the central station men indicates that low-voltage cables may be operated at higher temperatures than were considered safe a few years ago. Whether this experience should be the basis of a modification of the existing rule, is a matter for debate.

It is to be hoped that the operating experience of the central station men will be satisfactorily correlated with the laboratory work of the manufacturers before a new standard is established.

CONDITION OF ELECTRIC RAILWAY INDUSTRY

P. H. Gadsden, President of the American Electric Railway Association, gives the following statement regarding the condition of the electric railway industry:

An official report on the national condition of the electric railway industry for the year ending January 1, 1921, just compiled by the American Electric Railway Association, indicates a gradual and steady approach to a stable basis.

This situation is largely due to the fact that regulatory bodies, recognizing that granting of the claims of electric railways for fair rates of return is essential to the maintenance of good service, have steadily ordered relief throughout the country.

These regulatory bodies also seem to be cognizant of the fact that rehabilitation of lines will be a slow process and that at least the present advanced rates must be maintained for some time even if falling costs, anticipated but not realized as yet, should come. A large majority of the companies in the last four years have strained their financial resources to the limit, or created actual deficits, by merely meeting current expenses and making absolutely unavoidable emergency improvements. Many badly needed improvements have been deferred by virtually every company on account of a lack of funds. It is necessary therefore, now that fares are beginning to be commensurate with costs, that the present increased rates be continued until lines are fully rehabilitated. Unless present fares are maintained, indefinite suspension of extensions and betterments will result and this would be almost fatal to many properties.

The report just completed shows that 548 cities in the United States, representing more than 90 per cent of the riding population in cities, are paying fares ranging from 5 cents with a 1 cent transfer charge to a flat rate of 10 cents.

The immediate result of the widespread inclination to adjust rates upward to the requirements of good service is found in the low number of electric railway receiverships for 1920. There were only 16, representing a total capital stock of $25,313,655, as compared with 48 receiverships, representing a capital stock of $221,259,354, in 1919. During the year 450 miles of track were dismantled and 308 miles of track abandoned.

An Electromechanical Device for Rapid Schedule Harmonic Analysis of Complex Waves★

BY FREDERICK S. DELLENBAUGH, Jr.

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IMPROVEMENT in an art requires perfection of detail. Investigation of the details is often delayed, even though the procedure may be well understood, by the large amount of labor involved in handling cumbersome formulas or mathematical processes. The fundamentals of alternating-current theory are based upon a pure sine wave. More careful analysis considers waves formed of many multiple frequencies, which are found to exist in most practical applications. Thus not only the fundamental sine, but its higher harmonics, must be dealt with. The process of splitting up any known wave into its various components is well understood, but is slow and laborious if more than one or two harmonics are required. In present methods of analysis, it is at once striking how many combinations must be made to obtain the result. In mathematical methods this involves the calculation of a host of sums and products, elementary in form, but laborious in procedure. Methods of selected ordinates require many readings of ordinates from the curve, different sets being required for each harmonic. Graphical methods require a large amount of constructional detail. Machines involve changes of gears or pulleys, and many tracings of the curve.

The great ease with which electric circuits may be combined by multiple switches, and the accuracy with which electric measurements may be made, at once suggests the use of an electric network with some adjustable members to solve the curve under analysis (Bibl. 44). The device about to be described represents one way in which this may be done, and gives sufficient promise to indicate the possibility of great speed and reasonable accuracy with machines developed along these lines.

Theory

The electric analyzer is based upon the schedule method of analysis, so called because the mathematical processes may be combined in a schedule and save duplication of operations. The fundamental solution of Fourier's series, upon which it is based, may easily be derived as follows:

The series: $y = c_0 + \Sigma\, c_n \sin [n\,\theta + \psi_n]$ may be transformed to

$$y = c_0 + \Sigma\, [a_n \cos n\,\theta + b_n \sin n\,\theta]$$

When substitutions are made of:

$$c_n = \sqrt{a_n^2 + b_n^2} \qquad \text{and} \qquad \psi_n = \tan^{-1} [a_n/b_n]$$

In all of which expressions a, b and c represent coefficients of the different terms, n represents the order of the term, or harmonic, and is any integer, and θ represents the time function usually expressed by ωt. ψ is the phase angle of the harmonic, eliminated in the second expression by the introduction of both sine and cosine terms (Bibl. 4, 5, 6, 13 & 18).

If the area of the curve under analysis is the same on both sides of the zero line, then the term c_0 vanishes. If the curve is symmetrical with respect to its axis, then the even harmonics must be absent, and the values of n will be odd only. As these conditions are both true in most cases of alternating-current machinery, they will be the only ones herein considered.

By proper manipulation and integration, it is found that the coefficients sought are represented by the integrals:

$$a_k = 1/\pi \int y \cos k\,\theta\, d\,\theta$$

and

$$b_k = 1/\pi \int y \sin k\,\theta\, d\,\theta$$

where k is 1, 3, 5 etc.

In order to evaluate these integrals, an auxiliary curve may be obtained from the one under analysis by constructing curves of $y \sin k\,\theta\, d\,\theta$ and obtaining the area with a planimeter. This is the basis of many of the graphical methods. It also is possible to give a planimeter wheel such a motion that the vertical displacement is proportional to the values of y and the horizontal displacement is proportional to $\sin k\,\theta$ or $\cos k\,\theta$. In this case, the planimeter wheel will read the coefficient direct. This is the basis of most of the mechanical analyzers (Bibl. 65 & 82).

Both of these are indirect, however, and in order to obtain a direct mathematical method, further reduction of form must be obtained. It is shown in any text book upon the subject that the summation below represents the integral within certain limitations.

$$a_n/2 = 1/n\, \Sigma\, y_r \cos n/2\,\theta_r = 1/n\, \Sigma\, y_r \cos r\,\pi$$
$$a_k = 2/n\, \Sigma\, y_r \cos k\,\theta_r$$
$$b_k = 2/n\, \Sigma\, y_r \sin k\,\theta_r$$

All that is then necessary is to divide the curve into n equal parts, measure the $(n - 1)$ ordinates, multiply by the corresponding sine or cosine of the ordinate position, and add the results. The sum divided by

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★ This Electric Analyzer was designed and manufactured in the Research Division Laboratories of the Electrical Dept., Mass. Inst. of Technology, where it has been in successful use for some time.

$n/2$ will give the coefficient sought. The results are accurate, provided that there are no harmonics present of an order higher than the value of n.

The number of ordinates $(n-1)$ must be at least equal to the order of the highest harmonic, and, for waves containing only odd harmonics, need only be taken over one-half the wave. Thus for analyzing for the 1st, 3rd and 5th harmonics, the curve must be divided into six parts giving five ordinates, and if there are no harmonics present greater than the 5th, the results will be accurate within the error of measurement of the ordinates and of calculation. The method is quite old, and if worked out through all its stages, is quite laborious. It is interesting that Kintner (Bibl. 7) published a set of tables to help the calculations, but did not seem to see the duplications of effort later pointed out by Carl Runge (Bibl. 6 & 16). It is evident that since a large number of sines and cosines are used as multipliers, and as these are taken for definite recurring angles and multiples of angles, there must be a recurring sequence of functions used as multipliers. Runge thus showed that the total number of multipliers necessary was equal to the sines of the angles of division of the curve between 0 and 90. The data thus developed were put into engineering form by S. P. Thompson (Bibl. 10) and became the now familiar harmonic analysis schedule. An eleven-ordinate schedule capable of giving the 1st, 3rd, 5th, 7th, 9th and 11th harmonic, both sine and cosine terms, is given in the Appendix, Table XI.

Probably one of the most serious errors likely to occur in this method arises from the fact that the cosine terms are obtained from the differences of what may be large numbers, and therefore the condition exists where the differences consist of numbers smaller than the accuracy of the original products, and so may themselves be entirely due to error. Steinmetz (Bibl. 14) has worked out a modification of the schedule method to eliminate this source of error, but while mathematically successful, it increases the labor very greatly and so is not generally used. Another difficulty in practical application arises from the fact that higher harmonics are neglected, and a schedule must be adopted which includes a sufficient number of ordinates, so that the higher harmonics may actually be negligible. With an unknown curve, this is more or less guess work, although the highest harmonic present may sometimes be fairly accurately estimated, or the type of curve may be sufficiently familiar for the general magnitude of results to be known. Thus with the magnetizing current of transformers, it is generally known that unless saturations are carried to very high values, the harmonics above the 11th are extremely small, while with alternator wave shapes, a tooth harmonic may be observed as a ripple whose order may easily be estimated. If no ripple is observed, it is probable that no harmonics higher than the 13th exist. The labor required to solve a curve by the schedule method rises rapidly as the ordinates or harmonics increase. The rate of increase of labor is at least proportional to the square of the order of the highest harmonic. Schedules as high as 35 ordinates are given in the California Railroad Commission Report (Bibl. 21). F. W. Gover (Bibl. 18) has also furnished some interesting data upon the error to be expected from neglecting higher harmonics which are present. His results seem to indicate that unless the neglected harmonics are very prominent, the error is chiefly confined to the highest of the harmonics determined by the schedule method, but an analysis of a series such as given by a rectangular wave where the harmonics theoretically extend to infinity, and which requires a relatively large number of terms to approximate the curve, will give an error in all the harmonics determined by the schedule method for eleven ordinates, the error increasing in magnitude as the harmonics determined increase in order. In general, if the Schedule method is used intelligently, and with a knowledge of its limitations, it affords a very satisfactory method of analysis.

The Electric Analyzer

The new electric analyzer here described is based directly upon the schedule method, and is in substance an electrical network arranged to give the same result as that obtained by the mathematical processes. If an e. m. f. proportional to the ordinate y_r is impressed upon a conductance proportional to the sine or cosine of the ordinate angle $k\,\theta$, then the resulting current is proportional to their product, and it will be seen that this corresponds to one of the terms of the summation it is necessary to evaluate. Thus:

Let: $e = K_1\,y$ and $R = 1/\sin k\,\theta_r$

Then $I = K_1\,y \sin k\,\theta_r$

If a number of such circuits are connected in parallel, then the total current flowing will be the sum of the currents in each circuit. Thus, if a five-ordinate schedule is used as a basis, it will be necessary to have five adjustable voltages representing each of the measured ordinates, and a succession of resistances representing the various values of sines or cosines of the various angle multiples. As the ordinates remain the same for each curve, and only the angle functions change, it is evidently possible to have one setting of the adjustable voltages hold for the whole of one analysis, and the required values of resistance may be thrown in by multiple switches. In the use of the simpler schedules, dial switches may be used, but for more complicated schedules, gang switches are necessary to eliminate circulating currents. It will be understood that the current used for obtaining the solution of the schedule is direct current and bears no relation to the alternating-current wave under analysis. The analyzer does not analyze an alternating-current wave directly, but an oscillogram must first be taken of it and then ordinates measured at the proper in-

tervals, exactly as would be done for the mathematical schedule method.

The elementary principle is shown in Fig. 1, where three slide wires are used to provide the variable voltage and the sliders are connected from the sliding contacts through proper resistances to a common bus, to which is connected the indicating ammeter. Slide wires are the simplest means of obtaining variable voltage, but

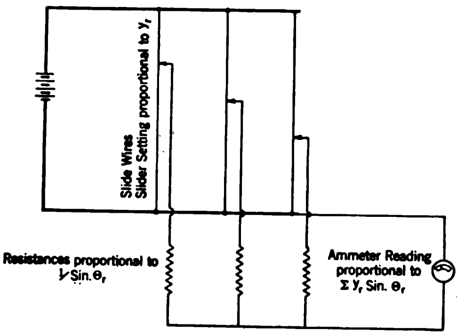

Fig. 1

of course are subject to the objection that if current is drawn off at the sliding contact, the voltage distribution is no longer linearly proportional. The error involved in the assumption that the voltage is proportional is given by the equation:

$$\text{Error} = \left(\frac{l - x}{x}\right) \frac{R\,x}{r\,l}$$

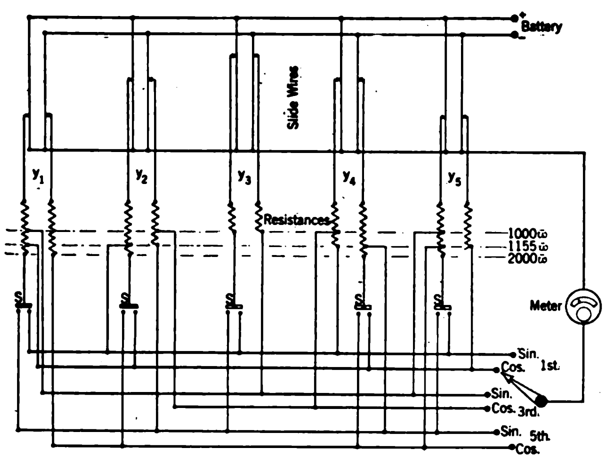

Fig. 2—Wiring Diagram for 5-Ordinate Analyser Giving 1st, 3rd, and 5th Harmonics

The dial-switch is turned to proper point and coefficient read on meter. The switches marked S, S, S, are mechanically coupled so that they move in unison and are thrown to the right for fundamental components and the left for 5th harmonic. Slide wires 2 ohms each.

where R is the resistance of the slide wire, r the resistance connected in series with sliding contact, x the position of contact and l the length of slide wire.

Thus it will be seen that if the series resistance is 500 times the slide wire resistance, the error is 0.1 per cent. As the accuracy of any harmonic analysis seldom exceeds 2 per cent, an error of 0.1 per cent is entirely negligible. Another point that brings in a difficulty is the fact that some of the angle functions are negative and some positive. Therefore, either the voltage or resistance must have two signs. Since negative resistance cannot be obtained for this purpose, it is easier to use a middle tap for the ammeter return circuit on each slide wire. As these middle taps will all be of the same polarity, there will be no current flowing and the position of the slider to the left or

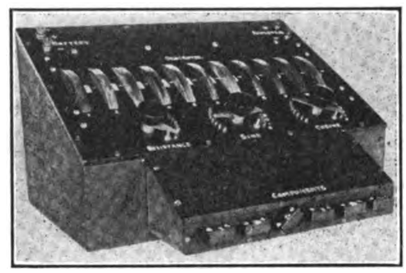

Fig. 3

right of the middle tap will give an e. m. f. of opposing signs. Fig. 2 shows the connections for a five-ordinate analyzer, the slide wires being folded back at the middle point and two sliders being used, so that they may both be attached to the same member of the device, and the same scale setting used for either positive or negative values, the change being made by switching in the resistance connected to the proper contact, leaving the other one idle. The values of resistance are calculated so that the maximum inherent error due to voltage distortion will be 0.1 per cent. The maximum will only occur in some of the ordinates and so the average error for the instrument will be less than this. The greater the number of slide wires, the less this average error will be. In order to calculate the values of the resistances, the lowest one is taken as 1000 ohms and the others designed to bear the same

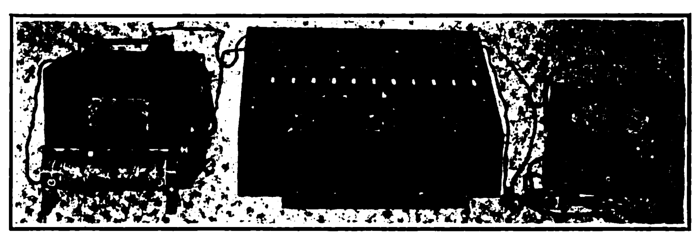

Fig. 4

proportion to this as the sine or cosine desired. Thus the smallest sine is 0.50. The largest is 1.00. Therefore, if the smallest resistance corresponding to the sine value of 1.0 is 1000 ohms, the largest resistance will be:

$$\frac{1.0}{0.5} \times 1000 = 2000 \text{ ohms}$$

The analyzer shown in Fig. 2 will analyze any wave not containing higher than the fifth harmonic and one where the wave does not cross the axis within

a half cycle, or, in other words, which has no negative ordinates, as no provision is made for ordinates of more than one sign. This may be taken care of very simply, however, by introducing a reversing switch in each slide wire, which is thrown over when a negative ordinate setting is required. The majority of curves met in ordinary practise do not require this additional refinement.

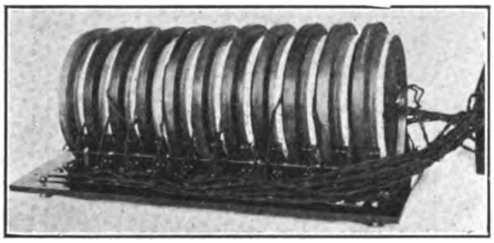

Fig. 5

Construction of Eleven-Ordinate Electric Analyzer

The eleven-ordinate analyzer based upon this scheme is shown complete in Fig. 3, and connected for operation in Fig. 4. The double slide wires, similar to those in the five-ordinate diagram, are wound upon maple plywood disks, six inches, (15.25 cm.) in diameter, with a projecting flange for manipulation. The edge of the disk carries a scale divided into 100 parts for the length of the slide wire, which is a little less than the periphery of 18.8 (47.8 cm.) inches. The three connections to each slide wire are made by flexible cables and carried to busbars along the under part of the face plate, as seen in the front part of Fig. 5, showing the slide wire disks assembled upon the face plate. Each disk projects through the face plate, and the scale reading against a setting line, painted on the face plate, is read through a one-inch slot beside the flange, as may be seen from Fig. 3. The sliding contacts are mounted upon a bakelite platform on the bottom of the face plate just behind the busbars, and consist of two phosphor-bronze springs per disk, bearing upon the two parts of the slide wire. The slide wires are made of No. 25 B. & S. resistance wire having 1.65 ohms resistance each, and, being connected in parallel, give the whole slide wire system a resistance of 0.15 ohms. The resistances representing the angle functions are placed along the inside of the containing box. The resistances are wound from high-resistance wire upon fiber spools 2½ inches (6.35 cm.) long, with ½-inch (1.27-cm.) cores and 1¼-inch (3.18-cm.) flanges. Each spool consists of two sections, the bottom section for connection to the negative contacts and the top section for connection to the positive contacts. For making the proper connections, six gang switches are mounted in a separate housing upon the front of the box, as shown in Fig. 3. These consist of a brass rod with five crossarms which fit between five sets of jaws upon each side. The jaws are all insulated from each other, so that closing the switch to either side, closes ten circuits and connects them to a common bus.

Each switch represents one harmonic, closed to the left for the sine component and to the right for the cosine component. In the position shown in Fig. 3, it is set for the fifth sine component. In this particular machine, two dial switches are also provided for further isolation of resistances. These are shown upon the front edge of the face plate in Fig. 3. These are entirely unnecessary for the operation of the machine and were added purely for experimental purposes to determine the errors resulting from circulating currents, with the point in view of further simplification. The third dial switch on the left is a resistance in the battery circuit for adjusting the slide wire current. The complete wiring diagram of this instrument is shown in Fig. 6, and the resistance data are given in the appendix.

Method of Operation

The current chosen for the slide wires depends upon the instruments available. In Fig. 4, the battery is connected through an auxiliary resistance for adjustment and about 0.20 ampere per slide wire was used in the tests given below. The meter for reading the harmonics was a Paul unipivot milliammeter, the scales of 20 and 2 milliamperes maximum being used. It does not make any appreciable difference what the resistance of the meter is, so a meter of this type is very convenient, as the sensitivity may be increased by multiples of ten by simply turning a switch; and thus

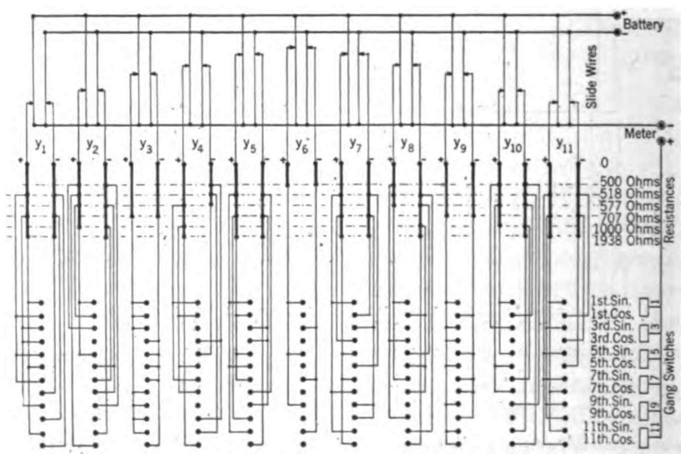

Fig. 6

the smaller harmonic components read with greater accuracy on the meter than is warranted by the method. If the current in the slide wires is increased five times, which is allowable, the meter required would be a 200-milliampere maximum reading instrument which is of commercial size. The slide wire current will still not be in excess of that easily furnished by a portable storage battery, so the auxiliary devices required are of easily obtainable nature.

To make the analysis, the instrument is first cali-

brated. This is done by setting the disks for a pure sine wave. Red marks are provided upon the scales, so that this can be rapidly done without reference tables. The first gang switch is then thrown to the left, or fundamental sine position, and the resistance in the battery circuit adjusted until the meter reads 100, or any other convenient amount. All other components should be zero. The switches are then turned successively through the other positions, and if the meter reads zero for all of them, it indicates that all connections are correct. This is a very rapid and invaluable check, for it can be made quickly any time and is an almost infallible indication of any open or short circuits, or poor contacts. All the resistances used in the sine fundamental position are used again in some other position, so that it includes them as well. Of course, it will not indicate poor connections, etc., that may develop for different ordinate settings but this has proved to be a very rare occurrence.

The eleven disks are next set to the values read from the curve, which should be done with some scale which will give the maximum ordinate a value of 80 to 100, or some decimal multiple of it, in order to insure the greatest range of slide wires, and thus obtain the maximum accuracy. If the battery current has remained the same, the readings obtained upon the meter will then give the values of the harmonic components directly, in terms of the fundamental sine wave used for calibration. Thus knowing the relative values of the scales used, the actual values of the coefficients may be easily determined. The readings are obtained by simply throwing one switch after the other, first to the left and then to the right, then returning it to the disconnected position and passing to the next switch. No change has to be made in the slide wire disk settings until another curve is analyzed.

Usually the relative magnitude of the harmonics is of more interest than the actual magnitude. This may be obtained directly from the instruments by adjusting the slide wire current, and this appears to be the only type of harmonic analyzer where this can be accomplished. After the disk settings have been made, instead of leaving the battery current the same as for the calibration and check, the fundamental switch is thrown to the sine position, and then the resistance in the battery circuit adjusted until the meter reads 100. Further manipulation of the switches then gives the harmonic coefficients directly in percentage of the fundamental sine. This machine also eliminates the chance of mathematical errors which creep in so easily with the multitude of operations necessary in the usual analysis by schedule.

Tests upon Electric Analyzer

The tables give a series of tests made to determine the accuracy of the network analyser. A very simple curve was first taken, as given in Table III. The only error will be seen to be the 11th sine coefficient. This is due to an error in the value of one of the resistances connected for this combination, and it will be noticed that this error is repeated in all readings. Increasingly trying combinations of terms were analyzed, and it will be seen that the maximum error occurs in Table IX, and amounts to 3.7 per cent. The value for comparison was obtained by working out the schedule method upon a calculating machine and thus obtaining the best possible accuracy by this method. It is interesting to note that in Tables IX and X for the triangular and rectangular waves, neither method gives accurate results, due to the harmonics above the 11th being neglected, and these types of curves having an infinite number of theoretical terms. Tables VII and VIII give the analyses of an ordinary transformer magnetizing current wave, and a peculiar wave made up of a sine with a superimposed discontinuous function obtained from the thermionic conduction in a three-electrode vacuum tube with alternating current impressed upon the plate circuit. These two curves are similar to the types met with in general practise, and show quite good accuracy, the maximum error being 3.32 per cent in the 11th harmonic and 1.88 per cent in the other harmonics. The last harmonic within range of the schedule will always give the largest chance for error as it means that only one point per cycle is determined, and this is just the requirement for determining the size of the component. Thus a small error in measurement of the ordinate or setting of the machine will introduce relatively large errors in the results.

From these tests and the underlying theory, the conclusion may be arrived at that for the usual type of curve an accuracy of 2 to 3 per cent may be expected from this type of instrument, which is sufficiently accurate for most practical requirements and compares

TABLE I

Data on Resistance Coils for 11-Ordinate Harmonic Analyzer.
Arrangement of Coils:

Coil No.	Resistance Taps.
	Top Sections. Plus Connection
1	0 — 518 — 707 — 1938
2	0 — 500 — 518 — 577 — 1000
3	0 — 707 —
4	0 — 577 — 1000 — 1938
5	0 — 518 — 707 — 1938
6	0 — 500
7	0 — 518 — 707 — 1938
8	0 — 500 — 577
9	0 — 707 —
10	0 — 500 — 577 — 1000
11	0 — 518 — 707 — 1938
	Bottom Sections. Minus Connection
1	0 — 518 — 707 — 1938
2	0 — 500 — 577 — 1000 — 1938
3	0 — 707
4	0 — 500 — 518 — 577
5	0 — 518 — 707 — 1938
6	0 — 500
7	0 — 518 — 707 — 1938
8	0 — 518 — 577 — 1000 — 1938
9	0 — 707
10	0 — 500 — 518 — 577 — 1000 — 1938
11	0 — 518 — 707 — 1938

TABLE II

Connections of Resistances for Different Components in 11-Ordinate Harmonic Analyzer.

Order of Harmonic	1		3		5		7		9		11	
Component:	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
Top Coils Plus Connection												
1	1938	518	707	707	518	1938	518	....	707	....	1938	....
2	1000	577	500	Inf.	1000	....	....	....	....	Inf	....	518
3	707	707	707	....	....	....	....	707	707	707	707	....
4	577	1000	Inf.	....	....	1000	577	1000	Inf.	....	....	1938
5	518	1938	....	....	1938	518	1938	....	....	707	518	....
6	500	Inf.	....	Inf.	500	Inf.	....	Inf.	500	Inf.	....	Inf.
7	518	....	....	707	1938	....	1938	518	....	....	518	1938
8	577	....	Inf.	500	....	....	577	....	Inf.	500	....	....
9	707	....	707	707	....	707	....	....	707	....	707	707
10	1000	....	500	Inf.	1000	577	....	577	....	Inf.	....	....
11	1938	....	707	....	518	....	518	1938	707	707	1938	518
Bottom Coils Minus Connection												
1		....	....	....	....	....	....	1938	....	707	....	518
2		....	....	Inf.	....	577	1000	577	500	Inf.	1938	....
3		....	....	707	707	707	707	....	....	....	....	707
4		....	Inf.	500	577	....	....	....	Inf	500	518	....
5		....	707	707	....	....	....	518	707	....	....	1938
6		Inf.	500	Inf.	....	Inf.	500	Inf.	....	Inf.	500	Inf.
7		1938	707	....	....	518	....	....	707	707	....	....
8		1000	Inf.	....	577	1000	....	1000	Inf.	....	518	1938
9		707	....	....	707	....	707	707	....	707	....	....
10		577	....	Inf.	....	....	1000	....	500	Inf.	1938	518
11		518	....	707	....	1938	....	....	....	....	....	....

TABLE III

Curve of Equation: $y = \sin\theta + 0.5 \sin 3\theta$

Ordinates:

y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.612	1.0	1.06	0.866	0.613	0.50	0.613	0.866	1.06	1.0	0.612

Harmonics	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.0	0	+ 0.9986	0	0	0
3rd.	+ 0.5	0	+ 0.4996	0	0	0
5th.	0	0	+ 0.0016	0	0	0
7th.	0	0	+ 0.0016	0	0	0
9th.	0	0	+ 0.0003	0	0	0
11th.	+ 0.02	0	− 0.0013	0	+ 2.0	0

TABLE IV

Curve of Equation: $y = \sin\theta + 0.8 \sin 3\theta + 0.6 \sin 5\theta + 0.4 \sin 7\theta + 0.2 \sin 9\theta + 0.1 \sin 11\theta$

Ordinates:

y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.978	0.587	0.388	0.297	0.307	0.250	0.307	0.297	0.388	0.587	0.978

Harmonics	Electric Analyser		Calculated		Error per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.0	0	+ 0.9987	0	0	0
3rd.	+ 0.80	0	+ 0.8081	0	0	0
5th.	+ 0.59	0	+ 0.6040	0	− 1.0	0
7th.	+ 0.38	0	+ 0.3884	0	− 2.0	0
9th.	+ 0.195	0	+ 0.1920	0	− 0.5	0
11th.	+ 0.12	+ 0.005	+ 0.0990	0	+ 2.0	+ 0.5

TABLE V

Curve of Equation: $y = \sin\theta - 0.8 \sin 3\theta + 0.6 \sin 5\theta - 0.4 \sin 7\theta + 0.2 \sin 9\theta - 0.1 \sin 11\theta$

Ordinates:

y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.0015	0.013	0.035	0.048	0.623	1.55	0.623	0.048	0.035	0.013	0.0015

(Actual values twice theses values)

Harmonics	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.0	0	+ 0.9998	0	0	0
3rd.	− 0.79	0	− 0.7980	0	− 1.0	0
5th.	+ 0.58	0	+ 0.5890	0	− 2.0	0
7th.	− 0.39	0	− 0.4030	0	− 1.0	0
9th.	+ 0.22	0	+ 0.2120	0	+ 2.0	0
11th.	− 0.12	0	− 0.1200	0	+ 2.0	0

TABLE VI

Curve of Equation: $y = \sin\theta + 0.2 \cos\theta + 0.5 \sin 3\theta + 0.1 \cos 3\theta + 0.1 \sin 9\theta + 0.2 \cos 9\theta$

Ordinates:

y_1	y	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.806	1.073	1.342	0.666	1.130	0.60	0.042	1.066	0.919	0.727	0.560

Harmonics	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.0	+ 0.18	+ 1.014	+ 0.189	0	+ 2.0
3rd	+ 0.49	− 0.10	+ 0.489	− 0.098	− 1.0	0
5th.	+ 0.018	+ 0.01	+ 0.004	+ 0.003	+ 1.8	+ 1.0
7th.	+ 0.023	− 0.028	+ 0.004	− 0.002	+ 2.3	+ 2.8
9th.	+ 0.013	+ 0.21	+ 0.090	+ 0.195	+ 3.0	+ 1.0
11th.	+ 0.011	− 0.023	+ 0.014	− 0.004	+ 1.1	+ 2.3

TABLE VII

Curve of magnetizing current in transformer

Ordinates:

y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.30	0.95	1.03	0.90	0.75	0.60	0.55	0.50	0.42	0.35	0.20

Harmonics	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 0.812	+ 0.22	+ 0.8121	+ 0.2165	0	0
3rd.	+ 0.199	− 0.160	+ 0.1933	− 0.1492	+ 0.74	+ 1.23
5th.	− 0.027	− 0.088	− 0.0280	− 0.0886	− 0.12	0
7th.	− 0.041	− 0.020	− 0.0407	− 0.0179	0	+ 2.45
9th.	− 0.041	+ 0.017	− 0.0401	+ 0.0158	+ 0.11	+ 0.12
11th.	+ 0.019	+ 0.038	+ 0.0086	+ 0.0233	+ 3.32	+ 1.85

TABLE VIII

Curve of Sinusoid plus discontinuous peak.

y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.60	0.725	0.775	0.775	0.725	0.65	0.75	1.07	1.25	1.15	0.725

Harmonics	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.065	− 0.165	+ 1.064	− 0.1630	0	+ 0.19
3rd.	+ 0.425	+ 0.098	+ 0.407	+ 0.0940	+ 1.7	+ 0.38
5th.	+ 0.037	+ 0.085	+ 0.037	+ 0.0833	0	+ 0.15
7th.	+ 0.044	− 0.012	+ 0.040	− 0.0098	+ 0.37	+ 0.19
9th.	+ 0 025	+ 0.005	+ 0.0009	+ 0.0050	+ 1.88	0
11th.	+ 0.037	− 0.020	+ 0.0024	− 0.0088	+ 3.30	+ 1.3

TABLE IX

Rectangular Wave:
$y = \sin\theta + 1/3 \sin 3\theta + 1/5 \sin 5\theta + 1/7 \sin 7\theta + \ldots\ldots$

Ordinates are all equal.

Harmonic	Electric analyser		Calculated		Error in per cent fundamental	
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.
1st.	+ 1.0	0	+ 1.000	0	0	0
3rd.	+ 0.325	0	+ 0.318	0	+ 0.3	0
5th.	+ 0.178	0	+ 0.172	0	+ 0.6	0
7th.	+ 0.099	0	+ 0.101	0	− 0.2	0
9th.	+ 0.058	0	+ 0.055	0	+ 0.3	0
11th.	+ 0.055	+ 0.014	+ 0.018	0	+ 3.7	+ 1.4

NOTE. Errors in above table are calculated against the calculated solution of the wave, since the fact that higher harmonics are neglected introduces large errors in the schedule method and the error figures are intended as a criterion of electric machine accuracy.

TABLE X

Triangular Wave: $y = 4/\pi\,(\sin\theta - 1/3^2 \sin 3\theta + 1/5^2 \sin 5\theta - \ldots\ldots)$

Ordinates:

y_1	y_2	y_3	y_4^m	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
0.262	0.524	0.785	1.05	1.31	1.57	1.31	1.05	0.785	0.524	0.262

Harmonic	Electric analyser		Calculated		Correct	Error per cent fundamental	
	Sin	Cos	Sin	Cos	Sin	Sin	Cos
1st.	+ 1.27	0	+ 1.2805	0	+ 1.2732	− 0.3	0
3rd.	− 0.143	0	− 0.1489	0	− 0.1415	+ 1.2	0
5th.	+ 0.058	0	+ 0.0588	0	+ 0.0509	+ 0.8	0
7th.	− 0.034	0	− 0.0346	0	− 0.0259	+ 0.8	0
9th.	+ 0.025	0	+ 0.0266	0	+ 0.0157	+ 0.9	0
11th.	− 0.018	− 0.001	− 0.0222	0	− 0.0105	+ 0.7	+ 0.1

NOTE. It will be noticed that the errors in the calculated values are of the same magnitude as those in the electric machine. The percentages given in the error column are calculated against the correct coefficients and therefore are chargeable in a large measure to the method rather than the electric device for interpreting it.

TABLE XI

SCHEDULE FOR THE ANALYSIS OF A PERIODIC CURVE IN WHICH ONLY ODD HARMONICS APPEAR UP TO THE ELEVENTH HARMONIC

Note. The two half-periods will be similar, so that if the mean line be taken between the highest and lowest points in the curve, there will be no constant term. For further simplification the origin should be taken where the curve crosses the zero line.

(1) Divide the half-period into 12 equal parts, and measure the 11 ordinates $y_1\ y_2\ y_3\ \ldots\ldots\ y_{11}$; y_0 and y_{12} being each zero.

(2) Then arrange these ordinates as under:

$$\begin{array}{llllll} y_1 & y_2 & y_3 & y_4 & y_5 & y_6 \\ y_{11} & y_{10} & y_9 & y_8 & y_7 & \\ \hline \end{array}$$

Adding.......................$s_1\ s_2\ s_3\ s_4\ s_5\ s_6$
Subtracting..................$d_1\ d_2\ d_3\ d_4\ d_5$

Note. s_1 stands for the sum of y_1 and y_{11}; d_1 for the difference between y_1 and y_{11}. Great care must be taken as to + and − signs throughout

(3) Group numbers, to obtain values for use with third and ninth harmonics, as follows:

$$\begin{aligned} s_1 + s_3 - s_5 &= r_1 \\ s_2 - s_6 &= r_2 \\ d_1 - d_2 - d_3 &= e_1 \end{aligned}$$

(4) Then select from the above numbers and put them in their places in the table below, *multiplying each by the sine set down in the left-hand column before it is entered.*

Angle	Sine-Terms			Cosine-Terms		
	Harmonics			Harmonics		
	1 & 11	3 & 9	5 & 7	1 & 11	3 & 9	5 & 7
Sin 15° = 0.2588	s_1		s_5	d_5		d_1
Sin 30° = 0.500	s_2		s_2	d_4		d_4
Sin 45° = 0.707	s_3	r_1	$-s_3$	d_3	e_1	$-d_3$
Sin 60° = 0.866	s_4		$-s_4$	d_2		$-d_2$
Sin 75° = 0.966	s_5		s_1	d_1		d_5
Sin 90° = 1.000	s_6	r_2	s_6	...	$-d_4$	...
Total first column	...	...	...	...	...	...
Total second column	...	...	...	...	...	...
Sum	6 B_1	6 B_3	6 B_5	6 A_1	6 A_3	6 A_5
Difference	6 B_{11}	6 B_9	6 B_7	6 A_{11}	6 A_9	6 A_7

Check:

$$A_1 + A_3 + A_5 + A_7 + A_9 + A_{11} = 0$$
$$B_1 - B_3 + B_5 - B_7 + B_9 - B_{11} = y_6$$

favorably with other methods of analysis. The error in the highest order of harmonic within range of the machine may be somewhat larger than this if the harmonic is prominent, but this is a characteristic of the method and not the particular instrument. The errors are all calculated against the value of the fundamental sine, as this is the fairest method. The importance of the harmonic is usually comparable with its relation to the fundamental, and any method of measurements from a curve cannot be expected to give great accuracy upon a harmonic which may have a magnitude of the same general order as the error of the method of obtaining the curve or the measurement of ordinates. When the great saving of time is considered, what might be called the overall effectiveness of the instrument is quite great.

Time Required for Harmonic Analysis by Different Methods

Harmonic analysis may be effected by three general methods:

1. Mathematical
2. Graphical
3. Instrumental

The time required by graphical methods renders them practically useless except for determining one or two harmonics. They have the advantage of picking out anyone harmonic within the accuracy of the construction, but do not seem to lend themselves readily to large groups of analyses.

The two best known instrumental methods are the Henrici-Coradi machine (Bibl. 55, 65) and the Westinghouse-Chubb polar analyser, (Bibl. 51 and 52). The former consists of five glass spheres, rolling within a carriage so that their displacement is proportional to the ordinates of the curve. The curve in cartesian form is plotted to fairly large scale and followed with a tracer point. Motion of the tracer point in the time-axis direction rotates cages around the glass spheres, the cages carrying planimeter wheels in contact with the spheres. Thus the radius of the circle upon which the planimeter wheel rolls is proportional to sin $k\theta$ and the motion of the spheres is proportional to y. The resulting displacement of the wheel is the solution of the Fourier integral given in the first part of the paper. Each cage carries two wheels at right angles. Thus for one tracing of the curve, the sine and cosine components of five harmonics may be determined. Resetting of the pulleys upon the top of the cages allows another five to be determined with another tracing of the curve.

The Westinghouse-Chubb analyser requires a curve in polar form, obtained from the polar oscillograph, from which a template must be made of cardboard. This is placed upon a platen, which is given a combined rotational and harmonic translational motion. An arm carrying a roller traverses the edge of the template and guides a polar planimeter in its extremity. After one complete trace of the template the reading of the planimeter gives one component of the harmonic for which the machine was set. Gears are then shifted for another harmonic and the process repeated. Unfortunately, the author has no records of time required for analysis by this machine. If high order harmonics are required, the time is rather long, but this is not fair to the machine, since it may easily be motor-driven and other work done while it is grinding out the analysis. Transferring curves from cartesian form to polar form requires a good deal of time and introduces a good deal of chance for error, so it is not satisfactory unless used with polar curves.

Some of the times required for analyses are as follows:

Method	Time	No. harmonics determined	Minutes per coeff.	Authority
Steinmetz........	10 hr.	10	60	D. C. Miller
Schedule.........	3 hr.	8	22.5	D. C. Miller
Schedule.........	1 hr.	8	7.5	F. W. Grover
Schedule.........	2.5 hr.	17	10.6	Author
Schedule.........	15 min.	3	5	D. C. Miller
Coradi Mch.......	13 min.	10	1.3	D. C. Miller
Coradi Mch.......	7 min.	5	1.4	D. C. Miller
Schedule..........	30 min.	6	5.0	Author
Electric Mch......	3.5 min.	6	.6	Author

The figures are not all comparable. They should be corrected for the number of harmonics determined, as the labor is not proportional with the different methods. The figures for the Coradi machine assume the curve already drawn. If the curve has to be enlarged from an oscillograph film, the added time for this should be included. The last two sets of data are based upon the time for doing the actual calculation, the readings from the curve having already been made, and being the same in each case, both times being for analysis of the same curve. The schedule analysis was performed upon a Marchant calculating machine. It can be done quicker with a slide rule, but the errors in the cosine components are then liable to be very great.

Concluding Comparison

In conclusion, it may be of interest to compare the advantages and disadvantages of the different methods.

SCHEDULE METHOD

ADVANTAGES	DISADVANTAGES
Simple	Very laborious and slow for more than a few coefficients.
Requires only a small chart for direction.	Not accurate where harmonics exist outside range of schedule.
Fairly accurate within theoretical limitations.	Subject to error unless calculating machine used, particularly in cosine components.
Reasonably fast for a small number of coefficients.	

WESTINGHOUSE-CHUBB

Accurate	Requires cardboard template of polar form.
Easy to operate	Difficult to use with curves in Cartesian form.
May be motor-driven and so require little labor.	Requires separate trace for each component.
Semi-portable	Moderately expensive.
Not difficult to obtain	Construction requires much machine work.
Easy to maintain	

HENRICI-CORADI

Accurate	Requires large curve.
Easy to operate	Special table, tracks, etc., must be provided.
Quick	Can only be manufactured by expert instrument makers.
Five harmonics completely determined with one trace.	Expensive.
	Difficult to obtain
	Requires care for maintenance.
	Not portable.

ELECTRIC

Easy and simple to operate.	Subject to limitations inherent with schedule method.
Moderately accurate and eliminates many chances for error.	Subject to usual difficulties of electric networks.
Very quick, as only one group of readings required from curve.	Not extremely accurate.
Reads coefficients either in actual values or per cent of fundamental sine component.	Number of resistances increases rapidly with order of harmonics.

Easy to construct, requiring common materials and little expert workmanship.	Requires storage battery and meter in addition to analyzer itself.
Inexpensive	
Easy to maintain	
Auxiliary apparatus of common form.	

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MOVING PLATFORMS FOR CROSSTOWN LINES

A moving platform to handle crosstown traffic in 14th, 42d and 57th streets, New York, was briefly described in a paper read by Mr. L. B. Stillwell last November at a meeting of the New York section of the American Society of Civil Engineers. Some further interesting details in regard to the proposed construction and method of electric drive have recently been published in the *Electric Railway Journal.*

The proposed electric carrier system of propulsion will permit the use of platforms mounted on car trucks, which will effect a material reduction in the cost of construction, operation and maintenance, and also of the space required. The distinguishing characteristic of this system is the method of propulsion. Instead of a complete motor being mounted upon the car and transmitting mechanical power therefrom through gears to the wheel, or driving carrier wheels on which the platform moves, the three-phase induction motor of the squirrel-cage type is used. These parts are separated, that corresponding to the stationary or primary element of the motor being straightened out into sections about 5 ft. long and placed midway between the rails in the roadbed, while that corresponding to the revolving element, also straightened out, forms a continuous short-circuited secondary mounted on the bottom of the car. The primary elements, when energized with three-phase current by induction, magnetize the short-circuited secondary which extends continuously along the bottom of the car. The result is that the force created between the induced secondary current and the shifting field of the primary propels the car.

The scheme proposed is to use three platforms of 27 in., 27 in. and 57 in. width, respectively, moving at 3, 6 and 9 mi. per hr. The high-speed platform carries seats for two persons spaced at 3-ft. intervals. It is proposed to use identical construction for the electrical elements on the three platforms, the different speeds being secured by operating the intermediate platform at double the frequency of the low-speed platform, and the high-speed platform at three times the frequency of the low-speed platform. All conductors and windings carrying power will be imbedded in the roadbed and thoroughly protected and insulated against damage by water in a manner to make accidental contact and danger very remote. The current will be carried at relatively high potential to transformers located at points along the system and thence by cables in ducts to the primary element between the rails. The primary element, as explained, is not continuous, but will be installed at intervals in sections about 5 ft. long.

The power supply will be produced by a motor generator set, in which a single motor will drive three generators mounted on a single shaft. The generators will produce three-phase alternating current at 10, 20 and 30 cycles respectively or some multiple of these frequencies. As the speed of the different platforms depends on the frequency of the three-phase current applied to the primary, it is clear that any platform may be operated at a lower speed by changing the frequency supplied to it, in case it should be desired to shut down one platform and operate the other two, or in case one platform only is to be operated.

The application of this system to the Forty-second Street loop would require three platforms, each approximately 10,100 ft. long. The seating capacity of the 9-mile platform would be 31,680 passengers per hour in each direction. The weight per seat for all three elements would be roughly 375 lb., while that of a loaded subway train is approximately 1,800 lb. per passenger.

Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low

BY L. L. ELDEN

Edison Electric Illuminating Co. of Boston.

PRESENT day practise in the operation of low-tension cables (7500 volts or less) is mainly based upon the temperature limitations generally specified by cable manufacturers and others, who from extensive experiments and research have determined the temperature at which the physical structure of impregnated paper as used for cable insulation, suffers marked deterioration in both its mechanical and electrical properties.

Naturally the conditions thus observed have formed the basis for certain guarantees on cable, a course which has had the support and approval of large users of cables as the result of their observations and experience. As the result of this experience there was evolved the present Standards rule limiting the permissible conductor temperature in low-tension paper insulated cable to 85 deg. cent., with suitable reductions in temperature as the voltage is increased. There being no evidence before us that paper insulation has suffered injury at a temperature as high as 85 deg. cent., and as this limit is slightly lower than the temperature at which paper has been noted to suffer deterioration (93.5 deg. cent.) we may, therefore, assume that low-tension cables may be safely operated up to 85 deg. cent. for indefinite periods without injury.

We find an apparent conflict with this temperature limitation in another Standards rule covering fibrous or Class A insulation when used for the insulation of electrical apparatus. This rule in specifying 90 deg. cent. as the permissible observable temperature for impregnated materials also permits an allowance of 15 deg. cent. for hot-spot correction or temperature gradient through the insulation, this raising the limit of conductor temperature to 105 deg. cent., or 20 deg. cent. higher than is specified for paper insulation in cables. For non-impregnated materials it is to be noted that this rule provides for a reduction of 10 deg. cent. in the above values.

It is questionable if the limit placed upon Class A insulation is not too high, since in the writer's experience it is possible to point out cases where Class A insulation has failed in modern apparatus, transformers and rotating machines, in which the temperature of the conductors has never been permitted to reach the observable limit of 90 deg. cent.

While the initial failure in these cases has been limited to a relatively small portion of the winding, the insulation on the balance of the winding has been found dried out to such a degree as to be too brittle to withstand the handling necessary to make replacements and an entire rewinding has been required.

There is a marked difference in the conditions under which insulation in electrical apparatus and in cables is operated. In electrical apparatus in general, excluding oil-cooled equipment, the insulation is largely exposed to the air at all times, and in many instances is cooled by forced ventilation, thus affording ideal conditions for the impregnating compounds between layers to be gradually dried out or expelled, leaving the entire body of the insulation to become more brittle as it is continued in service.

In the case of cable insulation wrapped in a waterproof covering or enclosed in a lead sheath, it may be contended that since evaporation is impossible, the insulating compounds will be retained in their original sticky or semi-fluid condition, and the insulation as a whole retain its original value if not otherwise injured.

This, however, is not always borne out in practise, as was noted recently when attempting to install some 1,500,000-cir. mil, 600-volt, single-conductor cable which had been held on the original reel as emergency stock for over ten years. The insulation on this cable, although never in service, was found to be too brittle to withstand installation.

Unfortunately, cables are not always laid in horizontal positions, thus affording opportunities for the compound to gravitate to the lower positions in the cable, leaving sections of cable at the higher levels free of compound and unsuited to heavy or maximum loading conditions. These conditions develop more rapidly in cables alternately heated and cooled, with resulting expansion of the sheath creating voids, thus permitting migration of the compound.

While these conditions are beyond the control of the user, he also must contend with the imperfections in manufacturing processes whereby the impregnation is sometimes imperfect, thus leaving dry sections of insulation which hazard the safety of cables so constructed when operated at the higher temperature limits.

Operating practise in the loading of low-tension paper-insulated cables as reported by various users varies so widely that it is impossible to draw exact conclusions or to establish any fixed rule as to the maximum temperature at which such cables may be safely operated.

Reports are presented from time to time showing that cables of sizes specified have successfully carried certain loads in amperes for stated periods either

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regularly or as occasion required, without apparent damage to the cables. The loadings thus specified have indicated that the commonly accepted ratings of such cables have been materially exceeded, even though the final effect on the cable could not be determined. Reports of such a character are valueless unless accompanied by the necessary supporting data clearly showing the conditions under which the record was made.

In the last analysis the sheath temperature is the only definite factor from which to determine the actual operating temperature of a cable, since the temperature of the conductor may be determined with a fair degree of accuracy from the sheath temperature.

It has been frequently suggested that the insulation normally used on heavy low-tension cables, 250 to 600 volts, while necessary for mechanical strength, is really unnecessary for the voltage employed, and that therefore a substantial amount of deterioration may occur without affecting the life of the cable.

If this view be accepted for low-tension cables, it cannot be accepted with the same degree of confidence for cables operating at 2300 - 4000 - 7500 volts, since in no case is the factor of safety, if based upon the thickness of insulation employed on the higher-voltage cables, in any manner comparable with that of low-tension cables.

To secure the same degree of safety the thickness of insulation must be increased many times, to do which is at once uneconomical and at times, a physical impossibility. That the same factor of safety is not attained in practise is amply demonstrated by the record of failures in cables from 2300 to 7500 volts, they being sufficiently numerous as to form a most powerful argument against any proposal to increase their loading by an increase in operating temperature.

For a number of years it has been customary to provide for very severe bending tests in all specifications under which the breakage of the paper insulation must be kept at a minimum. If as has been reported by a number of eminent investigators and cable manufacturers, paper when subjected to a temperature only slightly higher than 85 deg. cent (*viz.* 93.5 deg. cent) does actually become brittle and lose a substantial percentage of its original tensile strength, then it must of necessity be unable to withstand the bending tests specified for new cable.

Since it is not always possible to be sure that cable once laid, will never be disturbed or moved to new positions, it must follow that the users, when reinstalling cable which has been operated at temperatures sufficient to damage in some measure the insulation next to the conductors, must finally accept the cable in its new position under a materially reduced standard of perfection from that which was acceptable at the time of original installation.

If this is a fair statement, then it must be admitted that the original specification was too severe and that it is not unlikely that cables which may have been rejected under tests were at least as serviceable as cable reinstalled under the conditions suggested above.

To retain the present provisions for bending tests may therefore be regarded as an economic waste as reflected in the final cost of cable. It cannot be denied that if paper is subjected to high temperatures its useful life as insulation must gradually or rapidly be shortened as the case may be.

The real question for the cable user to decide is the rate of depreciation which he is willing to accept as the result of operating his cables at high temperatures. Various interests have contended for different rates of depreciation on underground plant, but it is contended by the writer that in specifying a rate to be applied to paper-insulated cable there should not be included any allowance for depreciation due to loading. Depreciation allowed for aside from any consideration of values at different periods should only include allowances for physical depreciation due to wear and tear in position, external injuries, electrolysis and similar agencies affecting the life of the cable sheath.

This point of view has been rigidly adhered to in the operations of the company with which the writer is connected in that loading of cables has been such that, so far as is known, the temperature limitation of 85 deg. cent. has not been exceeded. In the operation of its 230-volt d-c. system during the past eleven years, careful records of d-c. feeder loads have been maintained, from which the data in the following tabulation were obtained.

This record includes only those feeders which are composed either in whole or in part of one million single-conductor or one million concentric cables, and shows the number of hourly readings in excess of 800 amperes which have been observed each year. It is of interest to note that while a total of 75,800 readings have been noted in the eleven-year period, 53,040 or 70 per cent have occurred in the winter months, clearly indicating the seasonal load characteristics of the system which afford such favorable conditions for operating cables at relatively high load values during the period of lowest temperature.

In estimating probable temperatures from this record for comparison with the test records presented by Mr. Torchio allowance must be made for the lower sheath temperatures noted in this system, these resulting from uniformly lower earth temperatures and in some measure to the use of smaller conduit lines, none of which are sufficiently congested to create abnormal temperatures.

The relative values may be determined from a number of typical test readings here presented. Temperature readings were taken just inside ends of ducts in manholes and are comparable with readings taken from thermocouple No. 20 in Mr. Torchio's exhibit:

RECORD OF LOADS ON 230-VOLT D-C. FEEDERS—1910—1920
FIGURES IN TABLE INDICATE NUMBER OF HOURLY READINGS OBSERVED IN EXCESS OF 800 AMPERES

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals for year	No. of feeders observed
	800 to 900	920	160	120	200	80	0	0	100	20	380	440	600		
1910	900 to 1000	220	0	20	0	0	0	0	0	20	60	120	220	3900	32
	Over 1000	0	0	0	0	0	0	0	0	0	80	20	120		
	800 to 900	720	740	280	280	60	40	0	0	220	140	500	1360		
1911	900 to 1000	240	300	80	20	0	0	0	0	20	40	140	560	6140	36
	Over 1000	100	120	0	0	0	0	0	0	0	0	0	180		
	800 to 900	800	480	280	280	100	120	20	20	100	280	580	960		
1912	900 to 1000	420	120	200	80	100	40	0	0	0	200	140	280	6320	50
	Over 1000	60	200	60	60	60	0	0	0	0	60	60	160		
	800 to 900	400	140	940	80	120	60	20	0	160	120	660	460		
1913	900 to 1000	80	100	140	40	100	0	0	0	0	40	220	200	4240	39
	Over 1000	20	0	40	0	0	0	0	0	0	0	60	40		
	800 to 900	300	160	40	100	60	0	0	40	160	180	240	540		
1914	900 to 1000	60	20	0	0	0	0	0	0	20	20	60	60	2240	33
	Over 1000	40	0	0	0	0	0	0	0	120	20	0	0		
	800 to 900	240	160	180	40	20	60	0	0	40	420	340	760		
1915	900 to 1000	140	40	80	0	0	0	0	0	0	100	140	360	3280	33
	Over 1000	80	0	0	0	0	0	0	0	0	40	0	40		
	800 to 900	360	440	220	500	180	200	100	20	0	380	680	1020		
1916	900 to 1000	140	140	40	120	20	20	0	20	0	80	200	240	5400	46
	Over 1000	20	0	20	120	0	0	0	0	0	20	20	80		
	800 to 900	280	120	0	580	300	240	40	40	280	260	400	440		
1917	900 to 1000	120	140	0	20	20	0	0	0	0	20	120	100	3520	31
	Over 1000	0	0	0	0	0	0	0	0	0	0	0	0		
	800 to 900	120	520	360	460	280	380	220	140	100	880	680	1560		
1918	900 to 1000	0	80	100	80	100	120	0	20	140	160	280	680	7760	39
	Over 1000	0	60	0	0	0	0	0	0	40	20	60	120		
	800 to 900	900	1440	460	440	420	380	420	740	1040	960	1220	1300		
1919	900 to 1000	240	580	80	100	120	140	160	80	360	360	580	460	13540	57
	Over 1000	0	140	0	0	0	20	20	40	40	140	120	40		
	800 to 900	1560	880	1060	1600	1060	1640	1080	620	940	1260	1260	1000		
1920	900 to 1000	580	240	320	420	340	1080	60	220	580	300	440	240	19460	71
	Over 1000	140	0	40	0	140	80	0	20	140	40	60	20		
	800 to 900	6600	5240	3940	4560	2680	3120	1900	1720	3060	5260	7000	10000		
TOTAL	900 to 1000	2240	1760	1060	880	800	1400	220	340	1140	1380	2440	3400	75800	
	Over 1000	460	520	160	180	200	100	20	60	340	420	400	800		

Number of readings Oct. 1 to Mar. 31 = 53,040
Number of readings Apr. 1 to Sept. 30 = 22,760

Date	Load	Duration of load	Sheath temp.	Approx. temp. N. Y. cable sheaths with same loading. Thermocouple No. 20
Feb. 18, 1920	875 Amperes	6 hr.	16 deg. cent.	
Feb. 19, 1920	700 "	6 "	27 " "	
June 6, 1920	900 "	6 "	50 " "	
June 6, 1920	800 "	6 "	33 " "	60 deg. cent
June 6, 1920	800 "	6 "	39 " "	60 " "
June 6, 1920	700 "	6 "	43 " "	
Dec. 23, 1920	800 "	6 "	30 " "	60 " "
Dec. 23, 1920	890 "	6 "	33 " "	

Observations on June 6, 1920 were taken after four days of very hot weather.

Viewing these data in the light of our operating experience and allowing the usual temperature gradient through the insulation, it is questionable if the conductors of any of the cables under observation have ever reached a temperature of 85 deg. cent. unless due to local hot spots of which there has been no evidence.

Summarizing our experience with this installation, it appears that in eighteen years of use of single-conductor and concentric low-tension feeder cables there is no record of a failure of these cables due to loading conditions. This may be declared to be evidence of too great conservatism in the use of the plant investment in question. We believe, however, that it is justified by freedom from interruptions of service in a city where rendering the best possible service at all times is considered the first duty of the company.

With this record behind us, we are loath to depart from our present practise and approve a higher degree of loading which must invariably develop new troubles, until conclusive evidence is at hand which will justify increasing the present limit of 85 deg. cent. for low-tension cables as now incorporated in the Standards.

Viewing the data presented by Mr. Torchio in the

most liberal light, I cannot agree that it is conclusive since the physical condition of some of the sections of cable submitted after completion of his tests leaves much to be desired if the cable in question was to be continued in service. Further, the exhibit in question clearly shows the risk involved in basing the loading of cable upon temperature observations at one point. It is almost a foregone conclusion that as shown in this case there are points in any cable, where, due either to local conditions of external temperatures or to the effect of dry spots in cable insulation, excessive heating develops with resulting rapid deterioration and final destruction of the insulation. To operate low-tension cables at higher temperatures than at present is permissible cannot be all gain, since the carrying capacity of other cables within the same conduit must be reduced owing to the higher duct temperatures which must prevail. That such conditions are not unlikely to develop new troubles cannot be denied, therefore in the interest of safety to plant and avoidance of cable failures in general it seems the better policy to adhere to conservative temperature ratings rather than to operate at the highest possible temperature.

If, as seems quite likely, the existing temperature limit of 85 deg. cent. may be safely exceeded for short periods without injury to paper insulation, it would seem preferable to apply an overload rating to low-tension cables which may be taken advantage of as occasion requires rather than to operate such cables on a load factor basis.

The objection to the latter method lies in its impracticability of application to the operation of any system of distribution. In actual service each feeder operates on a load factor of its own which may or may not coincide with the system load factor, or whose maximum load period may be independent of the system peak load, hence each feeder must be treated as an individual case. Further, load factor makes no distinction between seasonal loadings, a most important factor in the operation of a cable system, since loadings which may be permissible in winter must be materially modified during summer periods. Finally while it may be possible to specify an allowable overload rating for this class of cables in terms of temperature, it is next to impossible to determine whether such limit is not exceeded in practise, a condition which should cause one to lean to a conservative standard such as the present Standards rule as the more desirable policy.

HUGE CABLE PROJECT IN SWEDEN

Twenty-four car loads of underground cable apparatus now on its way to Stockholm, Sweden, is part of a gigantic underground cable system which the Swedish Government intends to install between Stockholm and Goteborg. It w ll be 320 m les long. When t is completed, it will be the greatest underground cable line in Europe, and second in the world only to the 450 mile line now operating between Boston and Washington. It will be capable of carrying two hundred conversations simultaneously from Stockholm to its other terminus.

To complete the big Swedish project, it will be necessary to manufacture a total of 425,000,000 conductor feet of cable, 25,000 loading coils and 8 repeater stations with 300 repeaters.

Mr. A. H. Griswold, Assistant Chief Engineer of the International Western Electric Company who has just returned from Sweden where he has been making arrangements for the installation of the big cable line states that it will require about a year and a half to put the system into operat ng condition. The work will require about a thousand workmen in addition to a large staff of engineers.

An idea of the magnitude of the new Swedish line of communication can be gleaned from the fact that 6,500,000 pounds of lead and 3,350,000 of copper are being used in its manufacture.

INDUCTANCE COILS IN RADIO COMMUNICATION

The inductance coil is one of the fundamental elements in all radio circuits and improvements in the efficiency of radio systems depend very largely on the design and nature of these coils. There has been hitherto no comprehensive information available on the constants and behavior of such inductance coils. A careful research along these lines has been in progress at the Bureau of Standards having in view the use of coils both in practical radio operating circuits and as standards. The inductance, resistance, and capacity of typical coils have been measured and studies have been made of the theory governing their resistance and capacity. These quantities change with the frequency, and pre-determination of their value is of considerable importance in radio design. The results of this work have given formulas for calculating the capacities of short single-layer solenoids, pancake coils, and multi-layer coils of circular or square section and large diameter. Special design shielded coils of calculable capacity have been developed for use as standards.

Hysteresis Effects With Varying Superposed Magnetizing Forces

BY W. FONDILLER and W. H. MARTIN

Western Electric Co. Inc. American Telephone & Telegraph Co.

THE hysteresis effects discussed in this paper occur when magnetic fields are produced in iron by electrical circuits carrying simultaneously currents of different frequencies. Investigations have shown that when two currents of different frequencies are so superposed, the losses in the iron corresponding to each frequency may differ greatly from those obtained when each frequency is acting alone in the circuit. These effects are, therefore, particularly important in the electrical communication field because of the practise of transmitting over one circuit currents of different frequencies. Predictions of the behavior of iron-cored inductance coils and transformers in such a circuit may be erroneous if based on measurements of the iron losses which have been made in the usual way with single-frequency test currents.

These effects first became of importance in the plant of the Bell Telephone System as a result of the long established practise of arranging practically all the long telephone toll lines for simultaneous operation of telephone and telegraph circuits over the same wires. This system of "compositing" the lines has been generally arranged to provide one grounded telegraph circuit over each of the two conductors used for the telephone circuit. Each of these telegraph circuits can be operated either "full duplex" or "half duplex". In full-duplex operation a telegraph circuit is used to send messages simultaneously in both directions. In half-duplex operation the circuit is operated in only one direction at a time but may be used in either direction. Thus as many as four independent trains of direct-current telegraphic signals may be passing over the two conductors provided for the telephone circuit.

The compositing of a line is accomplished by the use of networks which transmit currents of frequencies in one range and discriminate against currents of frequencies in another range. A standard form of "composite set" is shown in Fig. 1. In the two wires of the line is inserted the network *a b c d*, consisting of inductances L_1 and capacitances C_1 and C_2, which transmits efficiently between the line and the telephone terminals, currents of frequencies in the range above 100 cycles. Connected to each of the line conductors are shown selective networks *a e* and *d f* each consisting of L_2 and C_1, which discriminate against this range of frequencies, but transmit efficiently the lower frequencies, including direct current, used for the operation of the telegraph circuit. Each of the line conductors thus provides a grounded telegraph circuit. To each telegraph terminal of the circuit is connected a duplex telegraph set which, by means of the usual balanced bridge arrangement, permits two-way operation.

With the application of this compositing system to loaded telephone lines[1] in which the inductance of the circuit is increased by the insertion at uniform intervals of toroidal iron-core inductance coils, it was observed that the operation of telegraph over long loaded circuits materially impaired the transmission of the telephonic currents. The effect was manifested by an irregular breaking up of the speech sounds which seriously interfered with the intelligibility of the telephone conversation, and in addition, the average volume of the received speech sounds was materially reduced. When a sound was sustained over the telephone system during operation of the telegraph circuits, a rapid undulation or fluttering of the tone was observed. This effect has become known as "flutter" and will be so designated here.

LINE TESTS

To obtain a quantitative measure of this flutter, tests were made to determine the effects which the telegraph currents had on the transmission of single-frequency currents in the telephone range. In what follows currents of frequencies in the range from 200 to 2000 cycles will be referred to as "telephone" or "audio-frequency" currents. Currents corresponding to the usual d-c. telegraph signals or single-frequency currents in the range from 0 to 100 cycles will be called "telegraph" or "low-frequency" currents.

For these tests, a circuit such as shown in Fig. 1 was employed. This circuit consists of a loaded telephone line at each terminal of which is connected the standard compositing arrangement for providing one duplex telegraph circuit over each conductor. The telephone apparatus at one end of the cable is replaced by an oscillator capable of sending into the line, cur-

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1. B. Gherardi. "Commercial Loading of Telephone Circuits in Bell System," TRANSACTIONS A. I. E. E. 1911, Vol. XXX, page 1743.

rents of frequencies in the telephone range. For recording the received current wave, there is connected to the other end of the telephone circuit an oscillo-

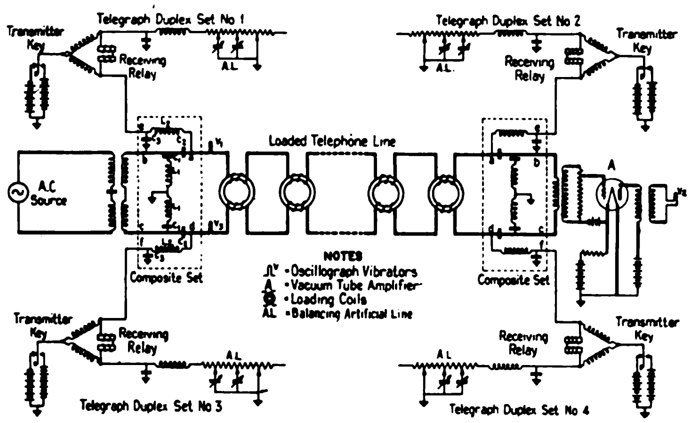

FIG. 1—COMPOSITED LOADED TELEPHONE LINE ARRANGED FOR RECORDING EFFECT OF TELEGRAPH OPERATION ON TRANSMISSION OF TELEPHONE CURRENTS

graph vibrator, V_2. This is operated through a step-down transformer or, in the later measurements of flutter, a multi-stage vacuum-tube amplifier, in order

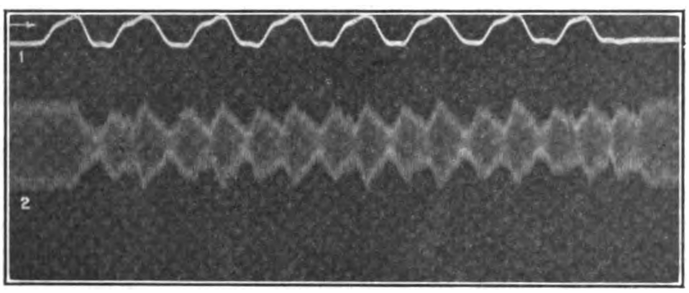

FIG. 2—FLUTTER EFFECT WITH CABLE CIRCUIT LOADED WITH INDUCTANCE COILS HAVING 60-PERMEABILITY CORES

V_1 Telegraph current, half duplex, 17 dots per second.
V_2 800 cycle telephone current.

to obtain enough current through the oscillograph to give suitable amplitudes on the records. The vibrators V_1 and V_3, of the oscillograph are connected directly

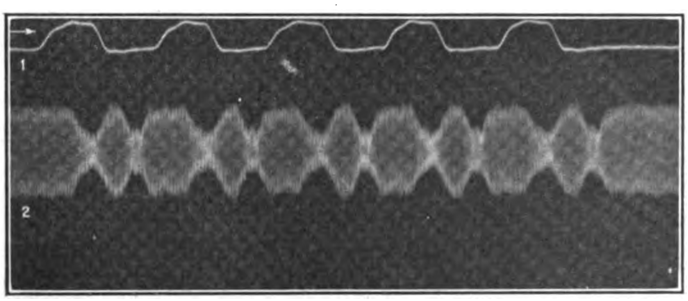

FIG. 3—FLUTTER EFFECT WITH CABLE CIRCUIT LOADED WITH INDUCTANCE COILS HAVING 60-PERMEABILITY CORES

V_1—Telegraph current, half duplex, 9 dots per second.
V_2—800-cycle telephone current.

into the line to record the telegraph currents over each conductor. The record of the telegraph current obtained is a combination of both the telegraph and the telephone current, but the magnitude of the latter is small compared to the former. With this circuit, data regarding the flutter are obtained by making oscillograph records of the single-frequency telephone cur-

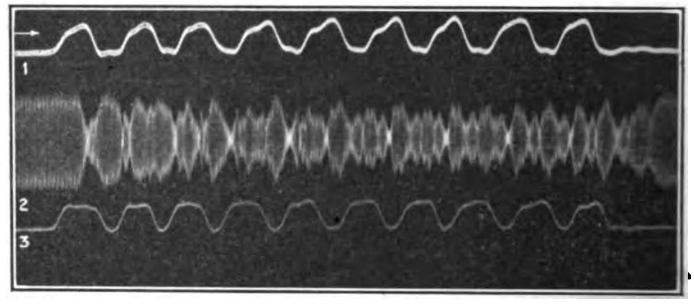

FIG. 4—FLUTTER EFFECT WITH CABLE CIRCUIT LOADED WITH INDUCTANCE COILS HAVING 60-PERMEABILITY CORES

V_1—Telegraph current, half duplex, 17 dots per second.
V_2—800-cycle telephone current.
V_3—Telegraph current, half duplex, 18 dots per second.

rent received over the line with the telegraph operating, and also with the telegraph not operating.

Such tests were made in 1912 in connection with a loaded telephone cable between New York and Phila-

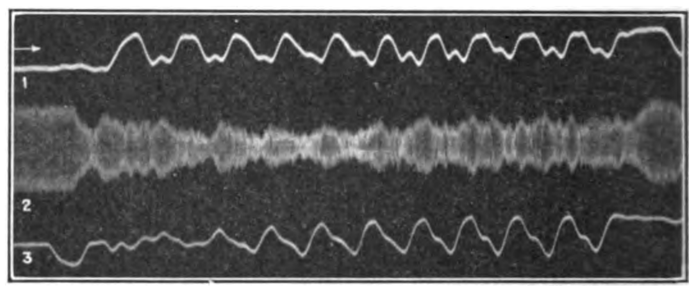

FIG. 5—FLUTTER EFFECT WITH CABLE CIRCUIT LOADED WITH INDUCTANCE COILS HAVING 60-PERMEABILITY CORES

V_1—Telegraph current, full duplex.
V_2—800-cycle telephone current.
V_3—Telegraph current, full duplex.

delphia of about 90 miles in length. In this cable, coils having an inductance of 0.25 henry are inserted at intervals of 1.25 miles. These "loading" coils are

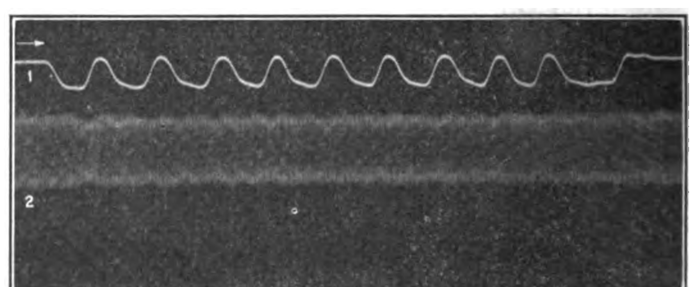

FIG. 6—FLUTTER EFFECT WITH CABLE CIRCUIT LOADED WITH INDUCTANCE COILS HAVING 30-PERMEABILITY CORES

V_1—Telegraph current, half duplex, 17 dots per second.
V_2—800-cycle telephone current.

of an early type developed for cable circuits. They were made up on toroidal cores consisting of a number of turns of fine iron wire. These cores have an effective

initial permeability of approximately 60. For a current of 800 cycles the ratio of received to sent currents over this circuit is about 0.31. The circuit has an attenuation per mile at this frequency of 0.013 and corresponds in its total attenuation effect to a length of 10.7 miles of standard No. 19 A. W. G. cable (88 ohms resistance and 0.054 microfarad capacitance per loop mile).

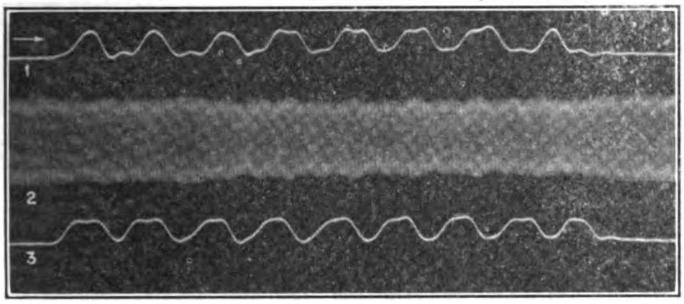

Fig. 7—Flutter Effect with Cable Circuit Loaded with Inductance Coils Having 30-Permeability Cores

V_1—Telegraph current, half duplex, 17 dots per second.
V_2—800-cycle telephone current
V_3—Telegraph current, half duplex, 18 dots per second.

Fig. 2 is an oscillogram showing the flutter obtained over a circuit in this cable with an 800-cycle telephone current of 0.002 ampere sent out on the line. The telegraph was operated in one direction over only one wire, that is, half duplex on one wire. The telegraph current is that corresponding to a succession of "dots" sent at a rate of 17 per second, and the maximum current reached is 0.055 ampere. The oscillogram was started with the telegraph not operating, and then by means of a commutator on the oscillograph the telegraph signals were placed on the line and removed near the end of the record.

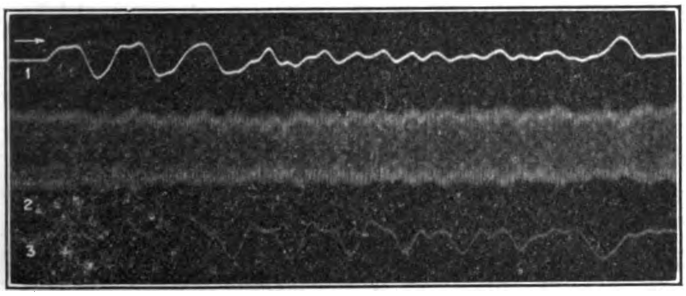

Fig. 8—Flutter Effect with Cable Circuit Loaded with Inductance Coils Having 30-Permeability Cores

V_1—Telegraph current, full duplex.
V_2—800-cycle telephone current.
V_3—Telegraph current, full duplex.

It will be noted that the 800-cycle wave is constant in amplitude at the start, but that during telegraph operation, the amplitude is at times materially reduced. Fig. 3 is a record of the same conditions as Fig. 2 with the exception that the frequency of the telegraph "dots" has been reduced to nine per second. From these records it is seen that a marked diminution of the 800-cycle wave is obtained at intervals corresponding to changes in the magnitude of the telegraph current, that is, when the telegraph current is increasing at the beginning of a telegraph signal or decreasing at the end of a signal. The time lag indicated on the oscillogram between a change in the telegraph current and the corresponding diminution in the telephone current is due to the fact that the telegraph record is taken at the sending end of the cable and the telephone at the receiving end. An appreciable time is required to propagate a wave over the loaded circuit.

Fig. 4 shows for the same circuit the effect of half-duplex telegraph operation on each wire of the telephone circuit, that is, one set of telegraph signals passing over each wire. The signals on the two wires are sent at slightly different speeds, (17 dots per second on the first wire, oscillograph vibrator V_1, and 18 dots per second on the second wire, vibrator V_3) and the flutter effect is rather irregular. The combined effect of the two sets of telegraph pulses is greater than that obtained on the oscillogram of Fig. 2.

Fig. 5 shows the effect with full-duplex telegraph operation over each wire, that is, when four sets of telegraph signals are simultaneously passing over the wires. In this case, also, each set of signals is a succession of dots. The records of the telegraph currents show for each wire the combination of the signal currents which are flowing in the two directions.

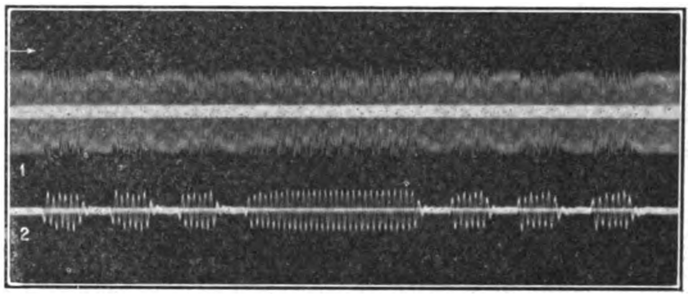

Fig. 9—Flutter Effect of 800-Cycle and 200-Cycle Currents Superposed on Loaded Cable Circuits

V_1—800-cycle current.
V_2—200-cycle current.

Figs. 6, 7 and 8 are oscillograms taken over a No. 13 A. W. G. cable circuit of the same length as that used for the above oscillograms but loaded with inductance coils of more recent design. These loading coils are made up on cores which have an effective initial permeability of about 30. The flutter effect with these coils is much smaller than that with the 60-permeability core coils.

Fig. 9 shows an oscillogram in which the telegraph current has been replaced by pulses of 200-cycle current. While the 200-cycle current is superposed there is on the average a diminution of the 800-cycle current received over the circuit. This oscillogram was taken over a different circuit from those described above and therefore the results are not directly comparable.

Two ratios may be used to express numerically the effects shown on these oscillograms. One is the ratio of the average amplitude of the high-frequency wave obtained during telegraph operation to the amplitude with the telegraph not working. The second is the ratio of the minimum amplitude obtained during telegraph operation to the amplitude of the undisturbed portion of the wave. The first ratio may be taken as a measure of the reduction in the volume of the transmitted speech sounds and the second as a measure of the distortion to which these sounds are subjected by the flutter.

Table 1 below gives these ratios for the oscillograms of Figs. 2, 4, 5, 6, 7 and 8, showing for both cable circuits the three conditions of tele raph operation namely, (1) half-duplex operation on one wire, (2) half-duplex operation on two wires, and (3) full-duplex operation on two wires.

TABLE I

Ratio of Amplitudes of Received 800-Cycle Current With and Without Telegraph Operation

Telegraph operation	60-Permeability coils		30-Permeability coils	
	Average amplitude	Minimum amplitude	Average amplitude	Minimum amplitude
1. Half-Duplex operation on one wire.........	0.63	0.34	0.92	0.81
2. Half-Duplex operation on two wires.........	0.53	0.11	0.90	0.78
3. Full-Duplex operation on two wires.........	0.42	0.08	0.88	0.75

Sim lar investigations of longer circuits have shown that the flutter effect increases with the length of the circuit. Its magnitude depends upon the type of loading coil, being less for coils having the lower permeability cores and a so for those with lower flux density in the core. Tests on loaded open wire lines showed results similar to, although materially smaller than, those obtained in cables. The loading coils in open wire lines are spaced about seven times as far apart as in cable and are made up on large cores.

It was observed, in addition, that the amount of flutter was affected by the following factors: The frequency and amplitude of the telephone current, the speed at which the telegraph signals are sent, and the amplitude and wave shape of the telegraph signals. By studying these factors, it was found that the diminution of the received telephone current increases as the frequency of the telephone current is increased, and for any frequency decreases as the amplitude is increased. When the speed of sending the telegraph signals is increased, or when the magnitude of the telegraph currents is increased, or when the rate of change of the telegraph current at the beginning and end of a signal is increased, the flutter in the telephone current becomes greater.

Since the flutter occurred only in loaded circuits, it was naturally assumed to be due to changes in the "constants" of the loading coils and therefore to changes in the total inductance or effective resistance of the circuits. The effects are transient changes in the magnitude of the received current or, since the current sent into the line is constant, there is a decrease in the ratio of the received to the sent current. Calling the received current I_2 and the sent current I_1, the relation between this ratio and the attenuation a per unit length of the circuit is given by the formula

$$\frac{I_2}{I_1} = e^{-la} \tag{1}$$

where e is the base of the natural logarithms and l is the length of the circuit. For telephone frequencies well below the critical frequency (that is, the frequency beyond which the coil loaded line has practically infinite attenuation) the attenuation constant is given by the relation

$$a = \sqrt{1/2\,\sqrt{(R^2 + p^2L^2)\,(G^2 + p^2C^2)} + 1/2\,(RG - p^2LC)} \tag{2}$$

in which R, L, C and G are respectively the total effective resistance, inductance, capacitance and conductance per unit length of the circuit and p is 2π times the frequency f. For the case of the loaded line, where $p\,L$ is large compared to R, a close approximation of equation (2) is

$$a = \frac{R}{2\sqrt{L/C}} + G/2\,\sqrt{L/C} \tag{3}$$

For the circuit having the 60-permeability core loading coils the first term on the right-hand side of this equation is about eight times as large as the second term and the former is therefore controlling. Neglecting this last term in equation (3), the change in attenuation may be caused by an increase in the resistance or a decrease in the inductance. Referring to the average reduction in the received current given in Table 1 for the oscillogram of Fig. 2, there would be required an average increase in the resistance per loading coil of 200 per cent, or reduction in the inductance per loading coil of about 60 per cent, to account for the attenuation obtained.

The characteristic impedance of a coil loaded telephone circuit for the frequencies for which the above attenuation formula applies is given by the relation:

$$Z_0 = \sqrt{\frac{R + j\,p\,L}{G + j\,p\,C}} \tag{4}$$

Since for telephone frequenc es $p\,L$ and $p\,C$ are large compared to R and G respectively, the relation may be reduced to the approximation

$$Z_0 = \sqrt{L/C} \tag{5}$$

Equation (5) shows that the impedance is affected by a change in the inductance of the loading coils, but, for the relative magnitudes of R and $p\,L$ stated above, is insensitive to changes in resistance. Measurements of the impedance of the loaded circuits for frequencies in the telephone range had shown only a

small change in the impedance when the telegraph was operated. On this basis then it is apparent that the flutter effect is not primarily the result of a change in inductance of the loading coils, but is due to a change in their effective resistance

Laboratory Tests

In the investigation to determine the explanation of this change in the resistance of the loading coils, consideration was given to data which had been accumulated on the various types of coils showing the effect of superposing direct current. The communication engineer is primarily interested in the inductance and effective resistance of a loading coil to alternating current within the range of telephone frequencies. A characteristic curve showing how the constants of a 60-permeability core coil are affected by superposed direct current is given in Fig. 10. The ordinates are

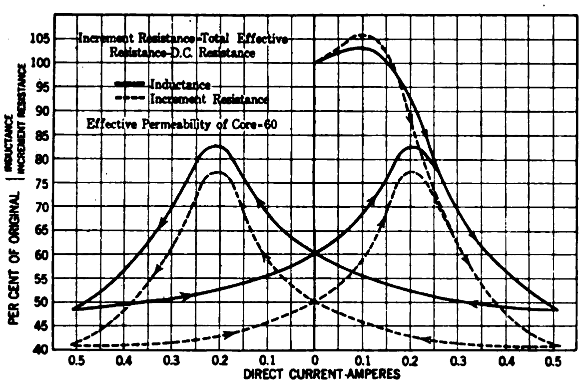

Fig. 10—Variation of Loading Coil Inductance and Effective Resistance with Cycles of Direct-Current Magnetization

percentages of the original inductance and effective resistance respectively, and the abscissas are strengths of superposed direct current in terms of current I or magnetic field H. The relationship was obtained by using a special bridge circuit which enabled superposing direct current on the alternating current. In this bridge the loading-coil core was subjected simultaneously to the action of a telephone frequency current and of a desired value of direct current.

The inductance and effective resistance of the loading coil were measured with a 1000-cycle current of 0.001 ampere. The values of L and R when there was no superposed direct current are taken as the original magnitudes from which the percentage change is calculated. In the curve of Fig. 10 the resistance which is plotted is not the effective resistance, but is the increment in resistance due to alternating current losses *i. e.*, the measured effective resistance less the direct-current resistance of the coil. From Fig. 10 it is seen that there is only a slight change in the inductance and effective resistance to the telephone current for a constant current strength not exceeding 0.1 ampere. For larger values of superposed direct current there is a marked decrease in both of these quantities.

The analysis of the attenuation and impedance relations of a coil loaded line which was given above indicated that the increased attenuation which accompanied the telegraph current could be accounted for only by substantial changes in the effective resistance or inductance of the loading coil. However,

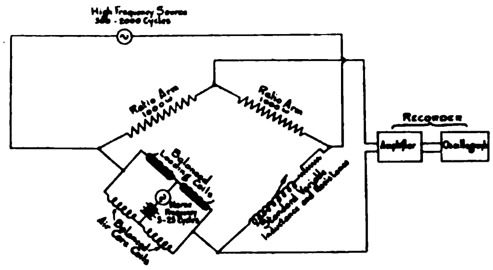

Fig. 11—Simplified Diagram of Special Bridge for Determining Flutter Effects

it has been standard practise in the plant of the Bell system, in order to guard against permanent magnetization of the coil cores, to limit the telegraph current to a maximum of 0.1 ampere. We need, therefore, consider only the part of the curve in the region from zero to 0.1 ampere direct current. For the oscillograms referred to above only that part between 0 and 0.055 ampere is pertinent, since the latter is the maximum value of telegraph current used. It is evident, that the percentage changes in these quantities shown in Fig. 10 would not account for the observed attenuation effects.

It is further to be noted that the magnetic conditions pictured in Fig. 10 are due to the simultaneous passage through the loading coil winding of an alternating current and a fixed value of direct current. The condition of the iron so far as concerns the superposed

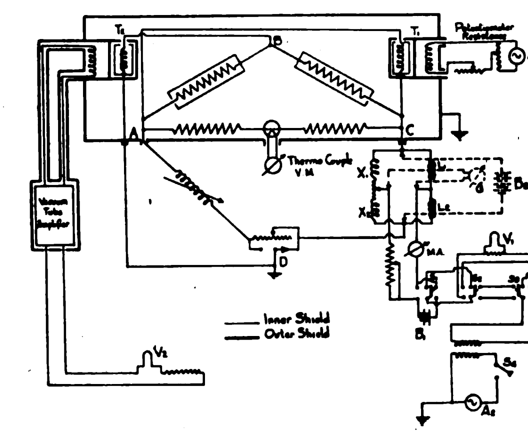

Fig. 12—Circuit of Special Bridge for Determining Flutter Effects

direct current is "static." In a composited telephone circuit, however, the loading coil has its audio-frequency magnetization superposed on iron which is in a "dynamic" state due to the changing magnetization which the telegraph current produces. Such considerations early indicated the necessity for devising means for

observing the effects on the loading-coil characteristics of the superposed magnetization due to telephone and telegraph current when both were passing through rapid cyclic changes.

It has long been known[2] that when an alternating magnetization is superposed on a slowly varying magnetization, the hysteresis loss of the latter is diminished. The energy expended in the iron to diminish this hysteresis must come from a source other than that of the low-frequency current. The flutter effect is recognized then as a manifestation of the interdependence of the high and low-frequency hysteresis losses. If, in any case of superposed magnetizations, there is a suppresion of hysteresis for one magnetization, there is found an accompanying complementary phenomenon, the flutter effect, in the higher frequency magnetization. The present paper we believe to be the first publication of quantitative information on the reaction on the higher-frequency circuit of the hysteresis suppression in the low-frequency circuit.

Mr. John Mills, an engineer of the Bell System whose analysis had indicated the importance of the resistance component, suggested a form of alternating-current bridge to investigate these transient or flutter effects. After considerable experimental work a form of alternating-current bridge was developed for the direct measurement of the effective resistance and inductance of the loading coils, for any desired instantaneous value of the superposed telegraph current.

Description of Flutter Bridge. A simplified diagram of the bridge is shown in Fig. 11. The actual circuit employed is shown in Fig. 12. Two similar coils are tested simultaneously in series. Bridge arms $A\,B$ and $B\,C$ are non-reactive 1000 ohm ratio arms. Arm $A\,D$ consists of a variable inductance of known effective resistance. Arm $C\,D$ comprises the coils which are under test together with an auxiliary circuit in the form of a secondary bridge. The variable resistance between arms $A\,D$ and $C\,D$ may be switched into either arm at will. The alternator A_2 is a source of telegraph current of a frequency of approximately 16 cycles. The recording system comprises an oscillograph and a multi-stage vacuum-tube amplifier through which the oscillograph is connected to the bridge circuit $B\,D$. The audio-frequency generator, A_1, and the recording circuit are connected to the bridge through double shielded transformers T_1 and T_2. The bridge itself is thoroughly shielded electrostatically in order to avoid false balances due to extraneous disturbances or unbalanced admittances to ground. The junction D is grounded so that under conditions of balance the terminals of the recording circuit are at ground potential.

The method of superposing the telegraph current on the secondary bridge circuit of arm $C\,D$ requires some detailed consideration. The magnetic material under investigation is the core of a toroidal inductance coil. Two such similar coils are wound and connected in series. These are designated X_1 and X_2 in the drawing. Two air-coils, L_1 and L_2, also balanced as to inductance and effective resistance, form the other two arms of the secondary bridge. The pair of junctions $X_1\,L_2$ and $X_2\,L_2$ are obviously points of zero difference of potential provided electromotive forces are impressed between the junctions $X_1\,X_2$ and $L_1\,L_2$.

In duplex telegraph operation over telephone lines the telegraph current in the line may have a variety of wave forms, as illustrated by the oscillograms of Figs. 2 and 5. Owing to the presence in the circuit of composite sets the telegraph pulses are rounded off. In the general case the telgraph current may be represented by an alternating current of low frequency.

In the operation of the flutter bridge the equivalent of a telegraph current is derived from a circuit comprising a generator and a battery in series. The generator gives an approximately sinusoidal wave and can be made to generate frequencies from 6 to 25 cycles per second. The e. m. f. of the battery is adjusted to equal the amplitude of the generator voltage. The series connection thus results in a current which pulsates between zero and a maximum positive value. The instantaneous current is, therefore, of the form $i = I_t\,(1 + \sin q\,t)$, where $q = 2\,\pi$ times the frequency of the generator and $2\,I_t$ is the maximum current output. This pulsating current was used instead of an alternating current, because it corresponds more closely to the wave form in half-duplex operation, which is in more general use than is full-duplex operation. It was also found to give more severe flutter than an alternating-current wave.

Special precautions are necessary to maintain the distribution of capacitances in the bridge circuit as a whole unchanged throughout the operation test. For this reason switches S_1 and S_4 are used to cut off the telegraph current without disconnecting any apparatus from the bridge. Switches S_2 and S_3 serve to pass the current through an oscillograph vibrator so that the telegraph wave may be observed and the relative values of the direct and alternating components properly adjusted. The milliameter $M\,A$ measures the telegraph current.

With the bridge circuit described, measurements of the instantaneous changes in inductance and effective resistance could be made with an accuracy of approximately 5 per cent.

In making the test it is necessary to observe the telegraph wave in its time relation to the current through the recording circuit. This is accomplished by having the low-frequency generator direct-coupled to the oscillograph mirror, thus making the telegraph wave "stand" in the field of view.

When the telegraph current is zero and the bridge is balanced to the telephone current, there will be no

2. F'nzi. *E ectrician* Vol. 26, p. 672, 1891, also, Gerosa and Finzi-Rendiconti del R Istituto Lombardo Vol. XXIV fasc. X April 1891.

difference of potential across the terminals $B\,D$. However, as soon as the telegraph current is applied a recurring unbalance is produced. The period of this phenomenon is double the frequency of the telegraph pulse.

It will be recognized that the bridge as described comprises sources of two frequencies, a balanced magnetic system which modulates the higher frequencies by the lower, and a bridge connection which transmits to the recording apparatus only the modulated current.

Operation of Bridge. The actual procedure in making a test is as follows: The main bridge is first balanced with the selected value of audio-frequency current of the desired frequency. The secondary bridge is also balanced for direct current after adjusting the current strength to the desired value. The telegraph current is then adjusted to the required strength and frequency by switching in the oscillograph vibrator V_1 which gives a standing wave on the scale in the oscillograph field of view. The telegraph current

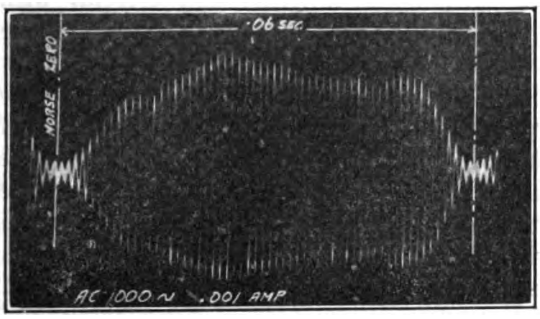

FIG. 13—RECORDER CURRENT WITH BRIDGE BALANCED FOR ZERO POINT OF TELEGRAPH WAVE

is then replaced in the oscillograph (using vibrator V_2) by the amplified current in the recording circuit, which is essentially the unbalanced audio-frequency current modulated by the telegraph current. During this observation switch S_2 is thrown to the right and S_3 to the left.

Fig. 13 is an oscillograph record of the unbalance current and shows the variations in its amplitude during the making of a telegraph "dot," *i. e.,* during one complete pulsation. It will be noted that the two constrictions occurring in the current are separated by a time interval corresponding to the frequency of the telegraph pulses, 16.6 cycles per second.

By suitable adjustment of L and R in the bridge arm $A\,D$, a balance can be obtained corresponding to any point of the telegraph wave, thus giving the instantaneous values of the effective resistance and inductance of the secondary bridge arm $C\,D$ corresponding to each point of the telegraph wave. The difference between these values and those required to balance at zero telegraph current are used to obtain the instantaneous changes in the iron-core coils by means of the following formulas:

$$\Delta R = \frac{\Delta R'}{2} \cdot \frac{(L_1 + L_2 + X_1 + X_2)}{(L_1 + L_2)^2} \qquad (6)$$

$$\Delta L = \frac{\Delta L'}{2} \cdot \frac{(L_1 + L_2 + X_1 + X_2)}{(L_1 + L_2)^2} \qquad (7)$$

where ΔR and ΔL are the changes in effective resistance and inductance respectively of the loading

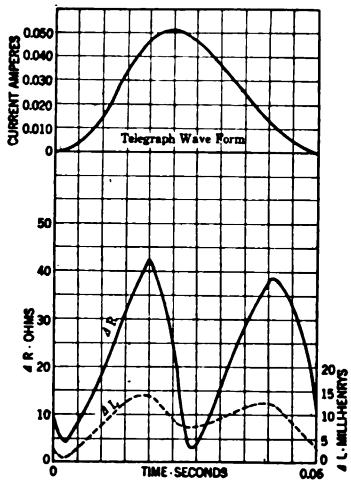

FIG. 14—VARIATION OF INCREMENTS OF EFFECTIVE RESISTANCE AND INDUCTANCE WITH PHASE OF TELEGRAPH CURRENT

coils, L_1 and L_2 are the inductances of the air-core coils, X_1 and X_2 are the inductances of the loading coils, $\Delta R'$ and $\Delta L'$ are the changes in resistance and inductance respectively, required to balance the bridge at the selected point of the telegraph wave.

These equations are an approximation as they neglect the resistance of the coils. This is permissible as the ratio of reactance to resistance in these coils at the test frequencies employed is very large (about 100:1).

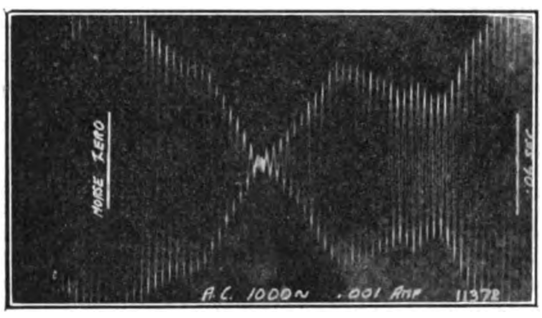

FIG. 15—RECORDER CURRENT WITH BRIDGE BALANCED AT FIRST PEAK OF ΔR CURVE OF FIG. 14.

Using this method the curve of Fig. 14 obtained. It will be seen that the changes from L_0 and R_0 during the interval of a single telegraph pulse take the form of a double peaked curve, the maximum values corresponding to the time in which the telegraph current is experiencing its greatest rate of change, the first when it is increasing and the second while it is decreas-

ing in value. In the upper part of the figure the telegraph wave is shown in its proper time relation to the flutter increments. Fig. 15 is an oscillogram of the recorder current, when the bridge is balanced for the part of the telegraph wave, corresponding to the first peak.

TABLE II

Flutter Effect with Varying Telephone Current in a 60-Permeability Core Coil. Constant Telegraph Current of 0.05 ampere, 16.6 cycles.

Telephone current (Frequency 1600 cycles)		Increments per henry in telephone circuit		
Current amperes	Magnetizing force H-c. g. s. units	Resistance ohms	Inductance millihenrys	Power loss watts $\times 10^{-}$
0.0005	0.023	780	74	195
0.0010	0.045	530	43	530
0.0015	0.068	390	29	880
0.0020	0.091	300	21	1200
0.0025	0.114	230	18	1438
0.0030	0.136	165	15	1485

TABLE III

Flutter Effect with Varying Telegraph Current in a 60-Permeability Core Coil. Constant Telephone Current of 0.001 ampere, 1600 Cycles.

Telegraph current (16.6 cycles)		Increments per henry in telephone circuit		
Current amperes	Magnetizing force H-c. g. s. units	Resistance ohms	Inductance millihenrys	Power loss watts $\times 10^{-4}$
0.01	0.48	37	3	37
0.02	0.96	105	8	105
0.03	1.44	200	14	200
0.04	1.92	340	22	340
0.05	2.40	500	39	500
0.06	2.88	660	67	660

TABLE IV

Flutter Effect with Varying Telephone Current in a 30-Permeability Core Coil. Constant Telegraph Current of 0.032 Ampere, 16.6 cycles

Telephone current (1600 cycles)		Increments per henry in telephone circuit		
Current amperes	Magnetizing force H-c. g. s. units	Resistance ohms	Inductance millihenrys	Power loss watts $\times 10^{-4}$
0.0005	0.035	180	39	45
0.0010	0.070	110	24	110
0.0015	0.106	80	18	180
0.0020	0.141	65	15	260
0.0025	0.176	60	14	375
0.0030	0.212	59	14	530

TABLE V

Flutter Effect with Varying Telegraph Current in a 30-Permeability Core Coil. Constant Telephone Current of 0.001 Ampere, 1600 Cycles

Telegraph current (16.6 cycles)		Increments per henry in telephone circuit		
Current amperes	Magnetizing force H-c. g. s. units	Resistance ohms	Inductance milihenrys	Power loss watts $\times 10^{-4}$
0.01	0,70	18	3	18
0.02	1.41	54	10	54
0.03	2.11	98	18	98
0.04	2.82	150	28	150
0.05	3.52	204	40	204
0.06	4.22	265	58	265

The curve of Fig. 14 shows the increments of effective resistance and of effective inductance during one cycle of telegraph current for a definite value of the high-frequency current. For the purposes of the present investigation it was important to ascertain the effect of varying the values of both the telegraph and the telephone frequency current. This was necessary in order to determine the laws for the variation of

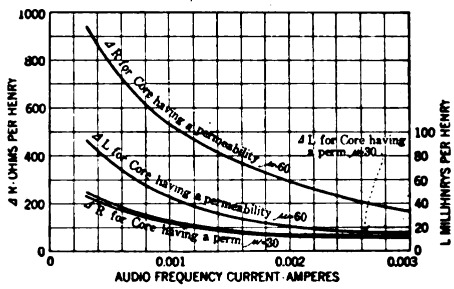

FIG. 16—VARIATION OF FLUTTER WITH TELEPHONE CURRENT

flutter, first with different telephone currents under fixed telegraphic conditions, and second, with different telegraph currents under fixed telephonic current. In making these tests only the peak values were recorded, as these are of the most importance in comparing different core materials for flutter effects. The data given in Tables II, III, IV, and V were thus obtained. The values of increment resistance and inductance are the averages of the two successive peak values.

The hysteresis losses for the 30 and 60-permeability core materials were determined for conditions of zero telegraph current from measurements over a range of telephone frequencies and current strengths. For

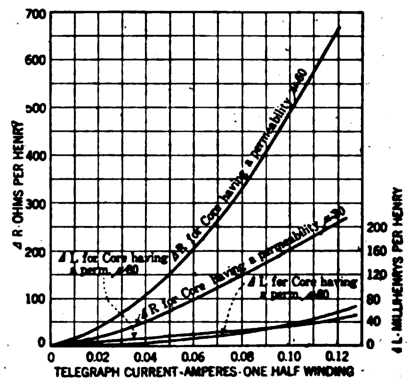

FIG. 17—VARIATION OF FLUTTER WITH TELEGRAPH CURRENT

the telephone conditions of Tables III and V, *i. e.*, 0.001 ampere and 1600 cycles, the total iron loss for the 60-permeability material was found to be 70 ohms per henry, of which 38 ohms is hysteresis loss. For the 30-permeability material the total loss is 37 ohms per henry, of which 17 ohms is hysteresis loss. It will be seen by reference to Table II that the resistance increment (peak value) due to flutter in the 60-permeability material is approximately 14 times the normal hysteresis loss resistance.

From the tabulated data the curves of Figs. 16 and 17 have been plotted. Fig 16 shows the relation of flutter to telephone current, while Fig. 17 shows the variation in flutter for a constant value of telephone current as the telegraph current is increased. The current values used for the latter curves are twice those given in the table for the reason that the telegraph current actually flowed through one-half of the coil winding. It will be noted that in these tests a telephone frequency of

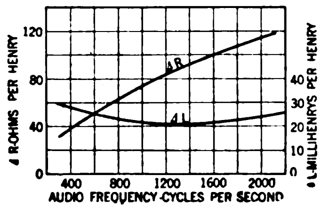

FIG. 18—VARYING AUDIO FREQUENCY

Telegraph current = 16.6 pulsations per second, 0.10 ampere in one line winding. Audio-frequency current, 0.001 ampere.

Curves show peak values.

1600 cycles was used. This frequency was chosen rather than the one usually considered as representative for telephonic measurements (*i. e.* 800 cycles) in order to magnify the flutter values, which increase with the frequency used. This is shown in Fig. 18 and 19, which give the flutter increments for varying telephone and telegraph frequencies respectively.

DISCUSSION OF RESULTS

In the experiments, the audio-frequency magnetizing force had, on the average, a value $H = 0.05$ *c. g. s.*, corresponding to a normal telephone current in the loading coil windings. This is a very small force, yet it exceeds that for which the molecular displacements may, according to Ewing's molecular theory,[3] be taken to be perfectly elastic, *i. e.* without hysteresis. The strength of audio-frequency current used develops only the initial permeability of the iron. The hysteresis loss in this region for hard iron is very small and can be detected only by careful bridge measurements. Such measurements can be used to separate the hysteresis from the eddy-current losses by the method referred to above.

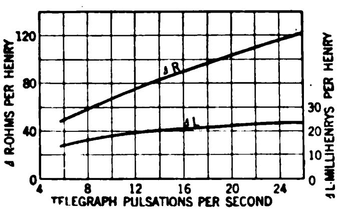

FIG. 19—VARYING TELEGRAPH FREQUENCY

Telegraph current = 0.10 ampere. Audio-frequency current = 0.001 ampere (1600 cycles per second).

Curves show peak values.

Computations based on a loss separation show that the increase in eddy-current loss due to the small increase in high-frequency inductance during the telegraph cycle would account for only a small fraction of the increased effective resistance. The balance of the increase must be charged to an augmented hysteresis loss. That such a loss is due to the high-frequency current assisting the low-frequency current to execute its hysteresis cycle is in accord with the work of previous investigators.

The results of the tests described above are summarized in part by the following empirical equation, which in terms of power, satisfies fairly well the ΔR curves of Figs. 16 and 17.

$$W/L_0 = k\, H_t^{1.6}\, H_{ac}^{\ 1.2}$$

in which,

W = maximum watts increment (taken as the product of ΔR and the square of the current for the corresponding point), for audio-frequency,

H_t = magnetizing force due to telegraph current,

H_{ac} = magnetizing force due to audio-frequency current.

The inference has already been drawn that the increased power loss in the high-frequency circuit represents a transfer of energy from the higher-frequency to the lower-frequency magnetization. It will be interesting therefore to review briefly the work of previous investigators on the subject of superposed magnetization in iron. The earliest work, already referred to, is that of Geroza and Finzi[4], who observed that there was a tendency to suppression of the hysteresis of a direct-current magnetization when alternating-current magnetization was superposed. In their experiments the direct-current magnetization was produced by a coil surrounding an iron wire, the alternating current having its path through this wire. The induction due to the current in the coil gave a "longitudinal" magnetization, while that due to the current in the iron wire produced a "circular" magnetization. These experiments also showed an increased initial slope of the *B-H* curve, indicating a greatly increased permeability of the iron to weak forces.

Maurain[5] in an investigation of the action of the Marconi magnetic detector made experiments in which the specimen was subjected to two longitudinal magnetizations, one due to direct current, the other to an oscillatory current. He found that under proper conditions the hysteresis could be completely suppressed in soft iron.

Probably the most striking experiments involving hysteresis effects were those by Madelung[6], who used a Braun tube to obtain on a flourescent screen the effect of superposing a rapidly oscillating magnetic force on the hysteresis cycle produced by a slowly varying magnetic force.

3. Ewing, Magnetic Induction in Iron and other Metals 1900, p. 302

4. Loc. cit.

5. C. Maurain. *Comptes Rendues*, Vol. 137, 914-916, 1903.

6. E. Madelung. *Annalen der Physik*, Vol. 17, 861, 1905.

Goldschmidt[7] investigated the effect of combined longitudinal and circular magnetization, the former being produced by direct current and the latter by an alternating current. He also remarked that the area by which the d-c. hysteresis loop is reduced exceeds that of the normal loop of the superposed circular magnetization. Waggoner and Freeman[8] examined the extent of hysteresis suppression with a superposed alternating longitudinal field for a series of iron-carbon alloys. The results showed the reduction of hysteresis to be proportional to the carbon content.

The present paper has dealt with the reaction in the high-frequency circuit instead of with the previously known effect on the low-frequency magnetization cycle. The basis for our conclusion that the so-called flutter in composited telephone circuits is complementary to a suppression of the hysteresis normal for a magnetization by telegraph currents, appears from the following restatement of our experimental results:

1. The resistance increment is proportional to the frequency of the telephone current.

2. It is proportional for different grades of iron to the hysteresis loss normal for these respective grades.

3. For larger telegraph loops having a greater average slope, the flutter loss increases correspondingly.

The findings of this investigation have been of immediate practical importance in the design of the plant of the Bell system. The fact that flutter depends upon hysteresis has led to the employment of materials of low intrinsic permeability in the coils used for loading the important long toll lines. The cross-sectional area of the core has been proportioned so as to work the iron at very low flux densities. These requirements affect also the design of other iron-cored induction coils and transformers which are used in circuits carrying currents of different frequencies.

For long loaded cable circuits there has been developed a telegraph system which has permitted a large reduction in the magnitude of the operating current. As a result of these factors the simultaneous operation of telegraph and telephone over a loaded cable circuit is satisfactorily free from flutter. A similar condition has also been obtained for the open wire lines.

It has been suggested that a current of frequency above the telephone range be superposed on the loaded lines to suppress the hysteresis and thereby reduce the iron losses for the telephone currents. This would tend to reduce also the flutter caused to the telephone currents by telegraph operation. This proposal was considered some years ago, but has difficulties in the way of its practical application. For instance, the frequency of the superposed current must be much higher than the frequency in the important telephone range to be effective. This would require that the spacing of the loading coils be decreased to transmit the higher-frequency waves, because the upper frequency limit of the transmission range of a coil loaded circuit is, for a given inductance per mile, inversely proportional to the spacing of the loading coils. There is also the problem of transmitting over very long circuits the amount of high-frequency power necessary to effectively suppress hysteresis.

Reference has been made to the presence of hysteresis suppression in the Marconi magnetic detector. The test results discussed above indicate that this suppression causes a power loss in the high-frequency circuit, which we have termed "flutter." These two effects, for flux densities well below saturation, are accompanied by a material change in permeability to the slowly varying magnetizing force. This change in permeability, it should be noted, is not merely that due to a shift along the normal magnetization curve, but results from a change in the form of the magnetization curve itself. The principle of operation of the various forms of magnetic amplifier and detector for radio telephony and telegraphy is such as to involve all of these actions.

The experiments described in this paper deal with two longitudinal magnetizations of different frequency and apply directly to conditions encountered in the telephone and telegraph plant. The determination of the actual form of the magnetization curve under the action of two magnetizations presents an interesting field for further investigation. The most direct mode of attack appears to be the use of the Braun tube to obtain the dynamic magnetization curve in a manner generally similar to that employed by Madelung. Such an investigation could well be directed toward obtaining accurate data as to the relation of the total hysteresis with two or more magnetic forces acting simultaneously to the hysteresis for each force acting alone. The investigation should include an examination of hard as well as soft iron, and determine the effect on B_{max} for both forces as well as the change in area of the hysteresis loops. With a number of superposed magnetic forces differing in their magnitudes and rates of change the further problem is presented of determining the interaction of any two of the forces in the presence of the others.

7. R. Goldschmidt. *E.T.Z.* 31, 218, 1910.

8. Waggoner and Freeman. *Gen. El. Review*, Vol. 21, 143, 1918.

NAVY DEPARTMENT STATEMENT

The electrical operation of the Navy's new line of six battle cruisers now building under 1916 naval program, will represent, according to Rear Admiral R. S. Griffin, Chief, Bureau of engineering, "The greatest horse power per shaft that has ever been projected in any marine installation irrespective of type of motive power."

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

THE MIDWINTER CONVENTION

As previously announced, the 9th Midwinter Convention of the A. I. E. E. will be held in New York City, February 16-18, in the Engineering Societies Building.

In addition to the technical sessions, the Entertainment Committee has provided for visits to various power plants on Wednesday afternoon, a dinner-dance at the Hotel Astor Thursday evening. The Edison Medal will be presented to Dr. Pupin Friday evening, and will be followed by a lecture by the medalist.

The registration office on the ground floor of the building will be open at 1.00 p.m. The opening technical session will be held in the main auditorium, and all of the other technical sessions in assembly room No. 1 on the fifth floor. The Edison Medal ceremonies and the lecture Friday evening will be in the auditorium.

The entire program is as follows:

PROGRAM

Wednesday Afternoon, February 16th

Registration office open, 1.00 p.m.
Board of Directors' Meeting, 3.30 p.m.
Inspection of local electrical plants.

Complete details will be furnished in the announcement to be mailed to the membership.

Wednesday Evening

Auditorium

TECHNCAL SESSION, 8:15 p.m.

Opening address by President Berresford.

"Present Day Practise Limitations of Oil Circuit Breakers" by H. R. Woodrow, Engineering Department, Stone & Webster.

"High-Current Tests on High-Tension Switchgear" by Philip Torchio, Chief Electrical Engineer, New York Edison Co.

Moving pictures and oscillograph records of switches at instant of failure will be shown.

Thursday Morning, February 17th

Assembly Room No. 1 Fifth Floor

TECHNICAL SESSION, 10:30 a.m.

"The Maximum Safe Operating Temperature of Low-Voltage Paper-Insulated Cables" by W. A. Del Mar, Chief Engineer, Habirshaw Electric Cable Co.

"Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low" by Philip Torchio, Chief Electrical Engineer, NewYork Edison Co.

"Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low" by D. W. Roper, Superintendent of Street Department, Commonwealth Edison Co.

Notes on "The Effect of Heat on Impregnated Paper from Cable Insulation" by W. S. Clarke, Engineer, Wire and Cables, General Electric Co.

"The Effect of Heat Upon Paper Insulation" by H. W. Fisher, Chief Engineer, Standard Underground Cable Co., and R. W. Atkinson, Assistant to Chief Engineer, Standard Underground Cable Co.

"Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low" by L. L. Elden, Electrical Engineer, The Edison Electric Illuminating Company of Boston.

Thursday Afternoon

Assembly Room No. 1, Fifth Floor

TECHNICAL SESSION 2.30 p.m.

"Carrier-Current Telephony and Telegraphy" by E. H. Colpitts, Assistant Chief Engineer, Western Electric Co., and O. B. Blackwell, Transmission Development Engineer, American Tel. & Tel. Co.

"Some Phases of Railroad Telegraph and Telephone Engineering" by Stanley Rhoads, Telegraph and Telephone Engineer, New York Central Lines.

Thursday Evening

Dinner Dance at Hotel Astor, 7:00 p.m. For details see under "Entertainment" following.

Friday Morning, February 18th

Assembly Room No. 1, Fifth Floor

TECHNICAL SESSION, 10:30 a.m.

"Regulation of Frequency for Measurement Purposes" by B. H. Smith, Engineering Department, Westinghouse Elec. & Mfg. Co.

"Measurement of Relative Eddy Current Losses in Stranded Cables" by J. A. Cook, Assistant Chief of Laboratory. New York Edison Co.

"An Electromagnetic Device for Rapid Schedule Harmonic Analysis of Complex Waves" by F. S. Dellenbaugh, Jr., Secretary, Research Division, Electrical Engineering Department, Massachusetts Institute of Technology.

"The Limitations of the Stopwatch as a Precision Instrument" by A. L. Ellis, Assistant Director, Thompson Laboratory, General Electric Co.

Friday Afternoon

Assembly Room No 1, Fifth Floor

TECHNICAL SESSION, 2:30 p.m.

"Short-Circuit Current of Induction Motors and Generators" by R. E. Doherty and E. T. Williamson, both of General Electric Co.

"Hysteresis Effects with Varying Superposed Magnetizing Forces" by W. Fondiller, Engineering Department, Western Electric Co. and W. H. Martin, Department of Development and Research, American Tel. & Tel. Co.

"Longitudinal and Transversal Heat Flow in Slot-Wound Armature Coils" by Carl J. Fechheimer, Research Engineer, Westinghouse Electric & Mfg. Co.

Friday Evening

AUDITORIUM

Presentation of the Edison Medal to Dr. M. I. Pupin,

Lecture, "Wave Transmission" by M. I. Pupin.

Discussing the losses of energy occasioned by the transmission of sound waves, electric waves and luminous waves through material media.

The lecture will be illustrated by experiments.

ENTERTAINMENT

Dinner—Dance

A dinner-dance will be held at the Hotel Astor, Broadway and 44th Street, New York, Thursday evening, February 17, 1921, at 7:00 o'clock. The purpose of the dinner-dance is to provide a social function for the entertainment of the members and their guests in attendance at the convention.

An informal reception will precede the dinner and prompt attendance is desired in order that the Entertainment Committee's arrangements may be carried out as planned.

The subscription price is $6.00 per person.

The tables will accommodate eight or ten persons each. Members are requested to make up their own tables and to state their seating preference to the committee. Communications should be addressed to the Committee on Entertainment, A. I. E. E., 33 West 39th Street, New York.

FUTURE A. I. E. E. MEETINGS

MARCH, NEW YORK

The 368th meeting of the A. I. E. E. will be held in New York, Friday evening, March 11th in the Engineering Societies Building.

The program will be under the auspices of the Power Stations Committee, and the subject of the meeting will be "Developments in Conversion Apparatus for Edison Systems." One main paper will be presented and will be followed by several prepared discussions.

APRIL, PITTSBURGH

The 369th meeting of the A. I. E. E. will be held on Saturday, April 16, 1921, in Pittsburgh, Pa. This will be a joint meeting with the Association of Iron and Steel Electrical Engineers and the general subject of the meeting will be "The Power Supply of the Pittsburgh District in Relation to the Steel Mill Industry."

Two papers will be presented on behalf of each of the participating societies. The A. I. E. E. papers are on the "New Colfax Station of the Duquesne Light Company—Electrical Features" by D. L. Galusha and the "Mechanical Features" by C. W. E. Clarke. The A. I. & S. E. E. papers are on the "Problems of Conversion from 60 Cycles to 25 Cycles" by B. G. Lamme, and "Some Results in the Change of 60-Cycle to 25-Cycles Energy by J. E. Fries.

The program includes a visit to the Colfax plant in the morning followed by luncheon; an afternoon session at which the papers on the Colfax plant will be presented and discussed; informal dinner, and an evening session at which the papers by Messrs. Lamme and Fries will be presented.

MAY, NEW YORK

The 370th meeting of the A. I. E. E. will be held in the Engineering Societies Building, New York, May 20, 1921. This is the Annual Meeting of the Institute, at which the result of the annual elections is announced and the report of the Board of Directors is presented.

FUTURE SECTION MEETING

Schenectady.—March 18, 1921. Subject: "European Economic and Industrial Situation." Speaker: Mr. D. B. Rushmore.

NEW YORK SECTION MEETING

On Friday evening, February 25, at 8 p. m., the New York Section of the Institute will hold a meeting in the Auditorium of the Engineering Societies Building, 33 West 39th St., New York. Dr. Saul Dushman, Research Laboratory General Electric Company, Schenectady, will deliver a lecture entitled "Habits of the Electron."

This lecture should appeal to those engineers who have not had time to go into the electron theory in all its details as it will be a presentation of the subject in as non-technical a manner as possible and will probably be accompanied by experimental demonstrations.

AKRON-CLEVELAND MEETING, JANUARY 14, 1921

The 366th meeting of the Institute was held in Akron and Cleveland on January 14th under the auspices of the Akron and Cleveland Sections and the Industrial and Domestic Power Sub-Committee on the Rubber Industry.

The Board of Directors met in Akron in the morning, and the Industrial and Domestic Power Committee also held a well attended meeting at the same time. Later in the morning special cars arrived from Cleveland bringing many of the Institute members from that city and vicinity. At noon, the 200 or more members and others present were the guests of the B. F. Goodrich Company at an excellent luncheon served in the cafeteria of that company. The lunch was preceded by a brief and exceedingly interesting address relating to the electrification of the Goodrich Plant by Mr. Vance of that company, followed by some interesting motion pictures.

After luncheon, those present were conducted in small groups by guides through the plant of the B. F. Goodrich Company, after which special cars were provided for conveying the party to Cleveland, where an informal dinner was served at the Hotel Statler at 6:30 p. m. Chairman A. M. MacCutcheon of the Cleveland Section presided, and a brief address was made by President Berresford.

The technical session began at 8:15 p. m., at which the paper previously published in the Institute JOURNAL on "Application of Electric Power in the Rubber Industry," prepared by the Sub-Committee on the Rubber Industry of the Industrial and Domestic Power Committee, was presented. A very interesting discussion followed and the meeting adjourned about 11:10 p. m.

The dinner and the technical session were held at the headquarters of the Cleveland Engineering Society, where every facility was provided for the comfort of those present. The officers of that society and the members of the Committee of Arrangements for the meeting are to be congratulated upon the satisfactory manner in which the entire program for the day and evening was planned and carried out.

A. I. E. E. DIRECTORS MEETING, JANUARY 14, 1921

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the headquarters of the Akron Chamber of Commerce, Akron, Ohio, Friday, January 14, 1921, at 9:45 a. m.

There were present: President A. W. Berresford, Milwaukee;

Vice-Presidents Charles S. Ruffner, New York, Charles Robbins, Pittsburgh, E. H. Martindale, Cleveland; Managers W. A. Del Mar, L. F. Morehouse, E. B. Craft, New York, F. F. Fowle, Chicago, James F. Lincoln, Cleveland; Secretary F. L. Hutchinson, New York.

The Board ratified the approval of the Finance Committee of monthly bills amounting to $14,929.21.

Reports were presented of meetings of the Board of Examiners held November 29, 1920, and January 3, 1921; and the actions taken on applications at those meetings were approved. Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 169 Students were ordered enrolled; 119 applicants were elected to the grade of Associate; 14 applicants were elected to the grade of Member; 18 applicants were transferred to the grade of Member; 3 applicants were transferred to the grade of Fellow.

The Meetings and Papers Committee reported upon plans for the following meetings: Midwinter Convention, February 16-18, New York, the program of which appears elsewhere in this issue; March 11, New York under the auspices of the Power Stations Committee—topic, "Developments in Conversion Apparatus for Edison Systems"; April 16, Pittsburgh, joint meeting with Association of Iron and Steel Electrical Engineers; May 20, Annual Meeting, New York.

The Board reaffirmed the action of the Board of Directors on February 26, 1914, to the effect that no committee meetings be held at hours which will conflict with technical sessions during Institute meetings or conventions. The Directors also voted that Institute committee meetings should in general be held during the latter, rather than the earlier, part of the week, whenever practicable.

The Committee on Coordination of Institute Activities reported the various actions taken by it at its meeting on December 4, 1920, including a recommendation that the policy be established of awarding prizes for the most worthy papers presented before the Institute. The Board approved the recommendation in principle and referred the matter back to the committee for the purpose of formulating a plan of procedure, including the method of making the awards, etc. The committee also recommended that in the future the Edison Medal and any other medals that may be awarded by the Institute, be presented to the medalists at the Midwinter or Annual Convention, preferably the former whenever feasible. This recommendation was approved.

A report was presented from the Edison Medal Committee announcing that the committee had awarded the Edison Medal for the year 1920 to Dr. Michael I. Pupin, for "his work in mathematical physics and its application to the electrical transmission of intelligence." (Arrangements have been made to present the medal to Dr. Pupin during the Midwinter Convention, on Friday evening, February 18.)

Mr. E. W. Rice, Jr., was reappointed a representative of the Institute on the Engineering Foundation Board for a term of three years, commencing February 10, 1921.

A communication from Mr. L. P. Alford, Temporary Executive Secretary of the American Engineering Council, was presented, calling attention to the fact that the employment activities had been transferred to the new organization and were being carried on by a temporary board consisting of the secretaries of the National Societies of Mining, Mechanical and Electrical Engineers; that the American Engineering Council had taken over the office of old Engineering Council in the McLachlen Building, Washington, where Mr. A. C. Oliphant is at present in charge; as Acting Assisting Secretary: and that a temporary office has been established at the Engineering Societies Biulding, New York City. Another communication from Mr. Alford gave the personnel of the principal committees of American Engineering Council already appointed, the chairmen of these committees being as follows: Constitution and By-Laws, Mr. W. B. Powell; Membership and Representation, Mr. J. F. Oberlin; Public Affairs, Mr. J. Parke Channing; Finance, Mr. Wm McClellan; Procedure, Mr. Calvert Townley; Publicity and Publications, Mr. L. P. Alford.

Secretary Hutchinson reported that at a meeting held January 13 the Secretaries of the four Founder Societies acting as the Board in control of the employment activities, had taken all necessary actions to terminate the existence of the former Engineering Societies Employment Service, this activity having been transferred, by action of the various boards of directors concerned, to the new American Engineering Council. The Secretary also reported that the Secretaries of the National Societies of Mechanical, Mining and Electrical Engineers were, upon request of the American Engineering Council, acting as a temporary board in charge of the employment activities; it being understood that at a later date this board will be enlarged by the inclusion of the secretaries of the various societies that are members of The Federated American Engineering Societies. The activity is continuing on practically the former basis, the finances being provided from the treasury of the American Engineering Council.

A final report was presented under date of November 27 from Charles F. Scott, Chairman of the Institute delegation upon the Joint Conference Committee; and the following actions were taken:

RESOLVED: That the report of the Chairman of the Institute's delegation on the Joint Conference Committee of the Founder Societies, under date of Novenber 27, 1920, be hereby accepted; and be it further

RESOLVED: That the Board of Directors of the American Institute of Electrical Engineers hereby places on record its hearty appreciation of the valuable services rendered to the Institute and the engineering profession generally by Messrs. Charles F. Scott, L. T. Robinson, and Calvert Townley in their capacity as representatives of the Institute upon the Joint Conference Committee representing the four Founder Societies, culminating in the recent organization of The Federated American Engineering Societies and the American Engineering Council.

RESOLVED: That the Board of Directors of the American Institute of Electrical Engineers hereby places on record its hearty appreciation of the valuable services to the engineering profession rendered by Mr. Richard L. Humphrey in his capacity as Chairman of the Joint Conference Committee of the Founder Societies, the efforts of which committee resulted in the recent organization of The Federated American Engineering Societies and its governing body, the American Engineering Council.

Mr. Ruffner reported upon the actions taken at the final meeting of Engineering Council, which has now terminated its existence, it being understood that all of its activities will be continued by the recently organized American Engineering Council.

In addition to these actions many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

INTEREST IN THE SHELDON MEMORIAL FOUNDATION GROWING

Interest and activity are growing in the Sheldon Memorial Foundation. The aim is to establish a fund of $100,000, the annual income of which is to go toward the founding of a chair in electrical engineering at the Brooklyn Polytechnic Institute, where Dr. Sheldon spent the thirty years preceding his death in organizing and enlarging the department of electrical engineering.

The movement for a memorial foundation was authorized and started at the Sheldon memorial exercises held last November in the Engineering Societies Building, under the direction of a committee of which T. C. Martin was chosen chairman.

An active campaign was started by these representatives in December to secure pledges and funds. Pledges from members of the professional societies, and from the Polytechnic trustees, alumni, students and friends, have already been received and are in excess of $25,000. Of this upward of $6,000

has so far been paid in. Now that the holidays are past, an intensive campaign is being pushed both in the electrical engineering field and in Brooklyn. Many contributions and pledges are being sent in voluntarily.

The treasurer of the fund, Charles E. Potts, is one of Dr. Sheldon's former students and a trustee of the Polytechnic Institute. He is receiving pledges and contributions daily at his office at 81 Franklin Street, New York City.

TELEGRAPH MEN WHO ARE MEMBERS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

The Blue-book of the American Institute of Electrical Engineers shows the names of 535 telegraph and telephone engineers as Fellows, Members or Associates.

A few of those directly engaged in telegraph work, who are identified with the Institute are:

In the service of the Western Union Telegraph Company: J. P. Edwards, R. E. Chetwood, H. W. Drake, G. M. Yorke, A. Lyons, M. H. Clapp, L. B. Bass, W. N. Fashbaugh, W. W. Drew, A. S. Dana, F. E. D'Humy, D. C. Brundage, E. R. Shute, A. Z. Mample, G. W. Janson, Everett Harvey, Thomas C. Harlan, L. H. Williams, M. A. Frye, J. E. Jenkins and J. W. Milnor.

In the service of the Postal Telegraph-Cable Company: J. P. O'Donohue, H. C. Shaw and John H. Mayer.

Others are: H. Hulatt, manager of telegraphs, Grand Trunk Railway, Montreal; Charles E. Davies, general superintendent of traffic, Great North Western Telegraph Company, Toronto; G. A. Cellar, general superintendent of telegraph, Pennsylvania Railroad, Philadelphia; Stanley Rhoads, telegraph and telephone engineer, New York Central Lines, New York; I. C. Forshee, electrical engineer, Pennsylvania Railroad, Philadelphia; H. L. Graham, Baltimore and Ohio Railroad, Jenkins, Ky; L. Behner, assistant superintendent of telegraph and signals, Pennsylvania Railroad, Pittsburgh, Pa.; G. H. Mayer, superintendent of telegraph, Soo Line, Stevens Point, Wis.; W. R. Birt, Southern Pacific Pailroad; M. A. Noss, engineer, Telepost Company, New York, and H. L. Krum, of the Morkrum Company, Chicago.

Telegraph engineers, wire chiefs and testing and regulating assistants who wish to identify themselves with the Institute may obtain application forms from Donald McNicol, chairman of the Telegraphy and Telephony Committee, 253 Broadway, New York.—*Telephone and Telegraph Age.*

AMERICAN ENGINEERING COUNCIL

ACTIVITIES ASSUMED

Beginning with the first of the year the transfer of activities of Engineering Council and the Engineering Societies Service (Employment) Bureau was made to American Engineering Council.

This means that American Engineering Council now has an office in Washington at the McLachlen Bldg., 10th and G. Sts., with Mr. A. C. Oliphant as acting Assistant Secretary in charge.

The Engineering Societies Service Bureau is being maintained in the Engineering Societies Building, 29 W. 39th St., New York City with Mr. Walter V. Brown in charge. At the outset it did not seem practicable to develop the permanent organization that is to direct this very important activity and which has such a close relationship with the secretarial responsibilities of the Member Societies of The Federated American Engineering Societies. Up to this time this service has been under the direction of the secretaries of the four Founder Societies, so temporarily it would seem wise to request the Secretaries of the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers and the American Institute of Electrical Engineers to form a Committee on Management to conduct the Service Bureau until such time as a permanent organization, under American Engineering Council, can be effected.

The Committee on Procedure of the Executive Board of American Engineering Council, when voting to take this employment service, specified that the applicants should be arranged in two groups, first, those who are members of Member Societies of The Federated American Engineering Societies, and second, all others. The text of the resolution in this regard reads as follows:

RESOLVED: That the Employment Bureau be continued by American Engineering Council on and after January 3, 1921, and that the Secretaries of the American Institute of Mining & Metallurgical Engineers, The American Society of Mechanical Engineers and the American Institute of Electrical Engineers be invited to act as Managers until such time as a more comprehensive plan can be formulated.

RESOLVED: That applicants for employment be divided into two classes—Preferred and Ordinary, the Preferred Applicants being those who are members of constituent societies of American Engineering Council and the Ordinary applicants all others.

It was thought that the best means to communicate with the secretaries of the Member Societies of The Federated American Engineering Societies would be by means of a regularly issued bulletin listing the positions open. This plan is to be carried into effect very shortly.

The American Engineering Council has temporary headquarters in New York City, and here, as well as in Washington, will be glad to serve the Member Societies and the individuals of Member Societies.

STANDING COMMITTEES

At the meeting of the Executive Board of American Engineering Council on December 17th, President Hoover announced the appointment of the following standing committees:

Constitution and By-laws. W. B. Powell, Chairman, C. F. Scott, D. S. Kimball.

Finance. Wm. McClellan, Chairman, E. Ludlow, C. Townley, L. W. Wallace, Ex-Officio.

Membership and Representation. J. F. Oberlin, Chairman, L. W. Wallace, A. S. Dwight.

Procedure. Calvert Townley, Chairman Herbert Hoover, Ex-Officio, W. E. Rolfe, D. S. Kimball, L. Parke Channing, L. W. Wallace. L. P. Alford.

Public Affairs. L. Parke Channing, Chairman, Fred J. Miller, L. B. Stillwell.

Publicity and Publications. L. P. Alford, Chairman, H. W. Buck, H. E. Howe.

At this meeting of the Executive Board the President was requested to invite the following existing committees of Engineering Council to continue their work and act as committees of American Engineering Council:

Classification and Compensation of Engineers, Cooperation with American Institute of Architects, National Board for Jurisdictional Awards in Building Industry, Military Affairs Committee, New York State Government Reorganization, Patents Committee, Payment for Estimating.

Russian-American Committee, Types of Government Contracts.

A Committee on the Elimination of Waste in Industry is being formed and the personnel of this committee will be announced later.

ENGINEERING COUNCIL

CLASSIFICATION AND COMPENSATION OF ENGINEERS

The Committee on Classification and Compensation of Engineers, which was reorganized on May 17 last, made a comprehensive survey of its activities and accomplishments in its final report to Engineering Council of December 6, 1920. The report, slightly condensed, follows:

Review of Activities in 1919

The Committee was originally organized early in April, 1919, and on December 18, 1919, it presented to Engineering Council a comprehensive review of the fields covered by the inquiry up to that time, and on the latter date Council adopted the classification. At that time five recommendations were made by the Committee, comprising the following:

1. The adoption of a classification of engineers in governmental and railroad services, and a tentative plan for compensation and promotion;
2. Advocacy of legislation for the registering of engineers;
3. Obtaining the views of heads of engineering bureaus and services as to the reasonableness of the proposed schedule of compensation;
4. Printing of an abstract of the report of the committee;
5. Appropriation of $10,000 for continuance of the Committee's work in 1920.

After prolonged discussion it was voted by the Council:

That the first recommendation of the committee be adopted, that the third, fourth and fifth recommendations be referred to the Executive Committee with power, except as to adoption of a plan for compensation of engineers (the Executive Committee later appropriated $3000 for use of the Committee), and that the classification proposed by the committee for engineers in governmental service be given prompt publicity.

Activities in 1920

The second stage of the work was organized with a view to bringing about a successful outcome through the stimulation of discussion and by obtaining publicity.

During the year 1920 a campaign was inaugurated on behalf of the classification adopted by Engineering Council with a view toward securing its general adoption and recognition as a standard for all branches of engineering service. To this end a communication together with an abstract of the December, 1919, report of the Committee was addressed during June and July,

(a) To the Secretary of each of 125 National, State and Local engineering or technical societies and of 24 Local Sections of the American Society of Civil Engineers, requesting each to endorse formally the classification, and to give the Committee the benefit of the views of the society or association and of its individual members as to the suitability of the scale of compensation and of the employment policy tentatively suggested,

(b) To each Chief Engineer of 52 engineering bureaus in the Federal Service, of 91 in State service, and of 99 in Municipal service, with a request for advice as to the practicability of immediately enforcing the classification, and as to the suitability of the scale of compensation and of the employment policy tentatively suggested, and

(c) To Governors of all States, to the Mayors of 69 leading cities, and the 5 Borough Presidents of New York City, 58 Secretaries of Civil Service Commissions, and a few non-technical heads of various Federal, State and Municipal deparments having jurisdiction over engineering work, urging official recognition of the classification, and asking for views as to the suitability of the scale of compensation and of the employment policy tentatively suggested.

From the 654 societies, associations and individuals addressed, 116 replies and acknowledgments have been received. These are distributed as shown in Table I.

TABLE I

	Addressed	Replying
Engineering Societies		
Society Secretaries	125	56
Local Sections Am. Soc. C. E.	24	9
Federal Service		
Bureau Heads	58	13
Engineering Heads	52	8
U. S. Civil Service Commission	1	..
President, Board of Commissioners, Washington, D. C.	1	..
State and Municipal Services		
Governors	48	3
Mayors (69 plus 5 Borough Presidents of N. Y. C.)	74	3
Civil Service Commissions	57	10
Engineering Heads of State Bureaus	91	5
Engineering Heads of Municipal Bureaus	99	8
Miscellaneous and Unclassified		
Various Individuals	24	1
Total	654	116

Copies of the communications sent out, mailing lists, and detailed summaries of replies are given in Appendices 1, 2 and 3. Endorsements and constructive criticisms are given in Appendices, 4, 5 and 6.

Summary of Canvass of Technical Societies

An analysis of the replies from society secretaries developed the following facts:

1. That to date the following named Societies, 13 in all, have endorsed the classification by formal action of the society as a whole or by action of its governing board,

   Albany Society of Civil Engineers,
   American Institute of Electrical Engineers,
   American Society for Testing Materials,
   Associated Engineering Societies of St. Louis,
   Colorado Society of Engineers,
   Engineering Association of Nashville,
   Engineers' Club of Columbus,
   Illinois Society of Engineers,—(Tentative Approval)
   The Municipal Engineers of the City of New York,
   The Society of Municipal Engineers of Philadelphia,
   Oregon Technical Council,
   St. Louis Section, Am. Soc. C. E.,
   Washington, (D. C.) Society of Engineers;

2. That of these 13 societies, 11 have adopted a compensation schedule of which 7 accepted the one proposed by the Committee, and 4 have recommended a higher schedule;
3. That 22 societies, including three founder societies have endorsement of the report of the Committee under consideration;
4. That action cannot be taken on the request of the Committee by many of the State and local societies before the winter of 1921 due to the fact that these societies have but one meeting a year;
5. That 18 societies of those addressed will not act in the matter on the ground that the subject is outside the scope of the organization or that the society does not feel qualified to voice an opinion;

Conclusions Drawn from General Canvass

An analysis of the replies received from all sources shows:

1. That endorsement of the classification is unanimous;
2. That where opinions have been expressed regarding the salary schedule, the proposed schedule has generally been endorsed, although it has been criticised on the one hand, on the ground that the compensation provided for the lower grades is

nadequate, while on the other hand, this same criticism has been made regarding the compensation for the higher grades;

3. That in those bureaus or departments where increases have been effected, the greatest increases in every case have gone to those in the lower grades, while only small increases or none at all have gone to the upper grades;

4. That a number of Federal officials and bureau chiefs, on the ground of expediency, are of the opinion that the work of the Congressional Joint Commission, although far from what is desired, should be supported, because through the setting up of a rational classification, it is clearly a step in advance of prevailing conditions;

5. That Civil Service Commissions especially have received the classification with favor;

6. That education of legislators and the general public to the important and indispensable services performed by the engineer is necessary;

7. That in many cases, salaries and titles in public service are fixed by statutes and cannot be changed without legislative action;

8. That many of the officials and engineers addressed fail to appreciate the fundamental character, the simplicity and the universal applicability of the classification proposed;

9. That there is no objection to the use of the terms, "Aid" and "Sub-Professional," on the grounds, respectively, that they do not convey the idea of an engineering engagement, and that they are distasteful to those without technical education or attainments. The former is evidently due to confusion of a *title* and a *grade*, and failure to appreciate that under the proposed classification, it is still possible to retain suitable titles for the positions occupied;

10. That the classification has actually been put into effect in the engineering bureaus of two cities, by one State Engineering Board, and by one city Civil Service Board, and that its adoption by another State Civil Service Commission is under consideration;

11. That engineering societies are not fully awake to the necessity of cooperation in this movement in order to make it successful;

12. That for proper stimulation of this movement, it is necessary to establish personal contact with representative engineers in various parts of the country and to impress upon each individual engineer his personal responsibility for bringing this subject to the attention of the public, in part through the proper upholding of the dignity and importance of the profession and in part through the assertion of the individual right to expect a suitable remuneration for valuable service.

Special Reports and Publicity Work

Part of the original program was carried out in that the services of Mr. Edmund I. Mitchell were engaged in conjunction with Engineering Council to handle the detail features of the work, to make investigations, and to advance the cause in such manner as could be done from the headquarters in New York. In his capacity as assistant Secretary, the Committee wishes in this connection to attest to the energy and thoroughness with which he has conducted this as well as the other branches of its work.

The Committee is of the belief that the campaign of education that it has conducted, has produced more and better results than the returns at hand indicate, and that its influence has reached those of whom it has no knowledge. The Committee has no method of measuring the results of the publicity work it has done, nor of the extent to which its recommendations have been followed by industrial concerns and engineering corporations.

Many copies of the report of December 1919 have been distributed in response to requests received by the Engineering Societies Service Bureau, and it has recently come to light that this report is being used extensively by the Vocational Guidance Department of the International Committee of the Y. M. C. A.

The California State Civil Service Commission has used our classification as the basis of an inquiry, concerning salaries for engineering positions paid by public and private organizations, which it is now conducting to determine what compensation should be paid by that State for different classes and grades of service.

The special reports and publicity items issued by the Committee are collected in Appendix 10, and an index of those published is given in Appendix 11.

While the work of the Committee has been hampered by lack of personal contact with influential forces in various sections of the country, several of its members have presented the subject before engineering bodies. The Chairman and Mr. Merrill have addressed the American Society of Civil Engineers, and the American Association of Engineers. The Chairman has also appeared before the Municipal Engineers of the City of New York, and the Brooklyn Engineers Club. The Secretary, Mr. Baker, has talked to engineering bodies in Boston, Rochester, Columbus and New York City.

Federal Service

In Appendix 7 is given a special report on the Federal Service, prepared under the direction of Mr. Merrill, Chairman of that Sub-Committee. Based upon the conclusions drawn from this report, the Committee believes that the present time is opportune to urge upon Congress an immediate radical revision upward of salaries paid for engineering service in order to arrest the disintegration of the engineering staffs of the National Government now progressing so rapidly. Revised compensation schedules should be based, in so far as practicable, upon the schedule suggested by the Committee.

Railroad Service

A special report of the Railroad Sub-Committee composed of Messrs. Morse and Parsons, is given in Appendix 8. The Committee recommends, in view of the suggestions made therein, that its successor confer with a similar Committee of the American Railway Engineering Association for the purpose of considering the practicability of adapting Engineering Council's classification to the railroad service.

Special Studies

During the year a special investigation has been conducted by Mr. R. S. Parsons to determine what relation, if any, exists between engineering charges and cost of work supervised. The results of this investigation are given in Appendix 9. The Committee is not prepared at this time to do more than recommend that this investigation be continued over as wide a field as practicable to the end that definite conclusions may be reached as to the practicability of fixing compensation on this basis.

Insufficient information has come to hand to enable the Committee to formulate an employment policy. Changing economic conditions make it unwise at this time to attempt to revise the proposed salary schedule put forth a year ago. These questions, along with others left open for discussion in our report of December, 1919, and new ones which have arisen during the year, will have to be left to our successors for further study.

Recommendations

After a careful survey of the whole subject, the Committee recommends:

1. That Engineering Council urge the appropriate Congressional Committee to take favorable action in the matter of providing for an immediate increase in the compensation of the engineering staffs of the Federal Government and to base this action, in so far as practicable, upon the compensation schedule suggested by the Committee on Classification and Compensation of Engineers;

2. That such Committee as may hereafter be constituted, be instructed to confer with a similar committee of the American Railway Engineering Association for the purpose of bringing about the acceptance of a common standard for the classification of engineers;

3. That owing to its vital importance the work of this Committee be continued by some suitable agency;

4. That the investigation to determine the relation between engineering charges to cost of work supervised be continued by such committee as may henceforth take over the work of this Committee:

5. That the present Committee on Classification and Compensation of Engineers be discharged.

Appendices*

The following appendices are made part of this report:

1. Mailing list, copies of letters sent to Society Secretaries, and summary of replies.
2. Mailing list, copy of letter sent to Engineering Heads of Federal, State and Municipal Bureaus, and summary of replies.
3. Mailing list, copy of letter sent to Governors, Mayors, Civil Service Commissions, etc., and summary of replies.
4. Endorsements by and constructive criticism from Societies.
5. Endorsements by and constructive criticism from the Federal Service.
6. Endorsement by and constructive criticism from State and Municipal Services.
7. Report of Federal Sub-Committee.
8. Report of Railroad Sub-Committee.
9. Study of relation of engineering charges to cost of work supervised.
10. Collection of reports and articles given publicity.
11. Index of published articles.

Respectfully submitted
(signed) ARTHUR S. TUTTLE,
Chairman
(signed) CHARLES WHITING BAKER,
Secretary

*Note: Any or all of the appendices will be sent upon request to Engineering Council, 33 West 39th Street, New York.

NATIONAL SERVICE DEPARTMENT

Excerpts from the final report of M. O. Leighton, of the National Service Department, Washington, D. C., to Engineering Council, follow:

December 6, 1920.

The National service work of the Washington office is increasing, and if and when its functions are turned over to the American Engineering Council, the latter will apparently catch the work at high tide.

Requests for information and assistance from the engineers of the country have increased at the rate of over 240 per cent since the report of October 16th. It is of interest to note that a large part of these inquiries continue to come from technical schools and colleges, and thus it is evident that Engineering Council is having a part in the education of engineers. Among the more important subjects of inquiry are the engineering projects of foreign countries, the census of industries for 1919, reports of the Interstate Commerce Commission on plans to reorganize railroad districts, service orders and decisions of the Interstate Commerce Commission, the University Extension movement, reports of special investigations by the Geological Survey, and the work of the Board of Surveys and Maps.

Starting with the issue of December 7th, the weekly bulletin was again increased to two pages so as to record the increased number of items of interest to engineers, caused by the convening of Congress.

Board of Surveys and Maps

One of the interesting events in connection with the work of this Board was the presentation of a second report of the standing Committee on Coordination, the first report having been unsatisfactory and referred back to the committee for further consideration. The second report was obviously an effort on the part of certain members of the Board, whose desire is to prevent or postpone the coordination of mapping work, to set forth the reasons why the present mapping situation in the Government is not as bad as represented. The proposal that was made would leave the mapping operations in almost as bad a condition as existed prior to the efforts of Engineering Council. Your representative addressed a letter to the Chairman of the Board drawing his attention to this feature of the report and protesting against its acceptance. It appeared that his sentiments agreed with those of the majority of the Board, with the result that the report has again been referred back to its authors.

Prospective Legislation

(*a*) *Patents.* The Joint Conference Committee of the two houses on the Patent Office bill have announced the holding of hearings as soon as practicable after the holiday recess, the selected date to be announced sufficiently far in advance to enable the Patent Committee of the American Engineering Council to make its arrangements to appear.

(*b*) *Appropriations.* Your Washington representative has not taken part in any of the hearings before the sub-committees of the Appropriations Committee of the House of Representatives with respect to any of the items that have been favorably regarded by Council. He did, however, have a conference with the Chairman of the Appropriations Committee in which the latter set forth the necessity for severe economy. The point was made that it has now become a matter of good citizenship for all persons considerate of the public welfare to avoid urging any expansion in government operations. Your representative therefore thought that it would be well to place the matter again before Council and to ask whether, in the opinion of Council, it would not be well to avoid urging any increase in Government appropriations not absolutely necessary to the integrity of the Federal structure. There is one item of special interest to engineers which perhaps may constitute an exception to the above. It is that of adequate appropriation for the Federal Power Commission. At the last meeting of Council your representative announced that under a decision of the Comptroller, there is no money available except that for the salary of the Secretary, and in view of the importance of the matter Council approved the recommendation that efforts be made to assist in securing a suitable sum.

(*c*) *Engineers in the Public Health Service.* The bill drawn in the office of the Surgeon General to raise the rank of the engineering staff has not yet been officially submitted to Congress. It is understood that this bill will not involve more than a nominal increase of expenditure and therefore may properly be supported by the present Council if it appears in Congress prior to the suspension of its work.

Department of Public Works

The National Public Works Department Association will suspend on January 1st next for lack of funds, and the residue remaining in its treasury—between $400 and $600—will probably be paid over to the United Engineering Society for disbursement to the underwriter. What shall become of the association is a question now being discussed by the members of its Executive Committee, and it is desired to present to you certain considerations that are being discussed.

On December 14th the House of Representatives passed what is known as the Smoot-Reavis Joint Resolution providing for a joint committee of Congress to investigate the Government organization and from time to time to bring in legislative bills for reorganization. This marks the end of active efforts as to general propaganda for the establishment of a department of public works. Subsequent efforts, if exerted, would naturally

be to assist the committee of Congress and to convince it as to the necessity for a public works department. To establish such a conviction will probably not be difficult. The principle has received general acceptance and in the many discussions, both formal and informal, that the writer has heard on the subject in Congressional circles and elsewhere there has been no instance of divided opinion as to the necessity for a public works department.

It is believed by the writer that the adoption of the Smoot-Reavis Resolution, which is now an accomplished fact, will facilitate rather than delay final action on a public works department. The joint committee of Congress has the whole field of executive work to review, but it will naturally reach its conclusions first on those functions of Government for which the case has been prepared, and the public works functions are the only ones which have received any mature and detailed study.

The writer is advised that it is the intention of Council to suspend its work on December 31st. This report is therefore the last one which the writer will have the pleasure of making to this body. He is exceedingly grateful for the trust and confidence which Engineering Council has conferred upon him during the past two years. No member of Council is more mindful of his errors of judgment and of action than he is himself, and he therefore appreciates more than he can express the patience and forbearance that have been shown by members of Council, and his service for that body will always be remembered as one of the most pleasant and instructive experiences of his life.

Very respectfully,
(signed) M. O. Leighton.

PERSONAL MENTION

Julian Loebenstein, formerly connected with the firm of Viele, Blackwell & Buck, has been appointed chief engineer of the Hopewell Insulation & Manufacturing Company, Inc., Hopewell, Va.

E. E. Stark, formerly City Electrical Engineer, Christchurch, New Zealand, has returned to this country, and recently visited the Institute headquarters in New York. His present address is 409 Park Avenue. Elyria, Ohio.

Wm. S. Higbie, formerly electrical inspector with Guggenheim Bros., 120 Broadway, New York, has resigned his position with that firm and has organized an inspection and purchasing service with offices at 114 Liberty Street, New York.

J. L. McQuarrie, Assistant Chief Engineer of the Western Electric Co. laboratories, New York City, who has just returned from the Orient, was decorated by the Emperor of Japan before he sailed for home. He received the order of the Rising Sun, Fifth Class, in recognition of his services in the telephone engineering field and the aid he has rendered in the development of Japanese transmission progress.

Hugh A. Brown has been appointed sales manager of the Electro Dynamic Company. He will have his office at the Bayonne, N. J. works, and will have entire charge of the marketing of the products. Mr. Brown has had an extended experience in sales work, having been connected with a number of electrical concerns, among them the Crocker-Wheeler Company and Burke Electric Company.

Henry R. King, formerly power and light sales manager of the General Sales Department, Western Electric Company, has become general sales manager for the M. S. Wright Company, which supplies vacuum cleaners to the Western Electric Company. Mr. King is an expert on power apparatus and his work with the Western Electric Company for the past 22 years has been practically devoted to that branch of the business.

Edward W. Tree, for the past two years Associate Editor of *Mechanical Engineering*, the Journal of the American Society of Mechanical Engineers, has resigned from that position to become Associate Editor of *Management Engineering*, a new technical periodical to be published by The Ronald Press Company of New York. Mr. Tree was formerly instructor in Electrical Engineering at the Polytechnic Institute, Brooklyn, from which institution he was graduated in 1916 with the degree of Electrical Engineer.

Frederic M. Brown and T. D. Holihan announce the organization of the Brown-Holihan Sales & Engineering Corporation. The corporation has taken on the business of Mr. Brown, dealer in new and rebuilt electrical apparatus. Mr. Brown will continue his connection with this organization along with Mr. Holihan, who was with the Syracuse Lighting Company for nine years, during which time he handled central station and substation engineering, construction, operating and power sales. The corporation is located at 406-408 South Franklin Street, Syracuse, N. Y.

William Baum, consulting industrial engineer, Holeproof Hosiery Company, formerly in charge of the Operating Research Bureau of The Milwaukee Electric Railway & Light Company, will open a consulting practise in Chicago, Ill. on January 3rd 1921 as William Baum & Company, Industrial Engineers. The newly established consulting firm will specialize in the development of industrial management systems and the betterment of industrial relations. Prior to Mr. Baum's connection with the Milwaukee Railway & Light Company, he was Dean of the School of Engineering of Milwaukee for two years and for thirteen years electrical engineer and European representative of the General Electric Company, Schenectady, New York.

OBITUARY

Kenneth L. Scranton, of Rochester, N. Y., died on December 30, 1920. Born at Perry, N. Y., on July 29, 1887, Mr. Scranton received his technical education in Buffalo, and since 1903 had had experience with various electrical concerns. He became an Associate of the Institute in 1919.

William Robinson, of Brooklyn, N. Y., died in that city on January 2, 1921. Dr. Robinson was born November 22, 1840, in Ireland, of Scotch-Irish and English descent. His education was received at Wesleyan University and Boston University, with the degrees of A. M. and Ph. D., his course including Electrical and Mechanical Engineering. He was an inventor and patentee of much note, especially in automatic electric signaling for railroads. Outside of this line, one of his best known inventions was the Robinson radial car truck, which was used extensively on electric railways. He also turned his attention to turbine engines, making several improvements on these. Dr. Robinson joined the Institute in 1909, becoming a Fellow in 1913.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (From Dec. 1-31, 1920)

Unless otherwise specified, books in this list have been presented by the publishers. The society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AIRCRAFT AND AUTOMOBILE MATERIALS OF CONSTRUCTION. Vol. 1. Ferrous Materials.

By Arthur W. Judge. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. 16+739 pp., illus., charts, tables, diagrams, 9x6 in., cloth, $9.00.

Contents: Stress, strain and elasticity.—The properties of materials under test.—Testing machines and methods.—The metallography of ferrous materials.—Irons and carbon steels. Alloy, or special steels.—Commercial forms of ferrous materials. The treatment of ferrous materials.—Heat treatment furnaces.—Pyrometry.—Metal joining processes.—The protection of metal surfaces.—Ferrous and other alloys.

This book has been written for the use of the ferrous materials employed in the construction of automobiles and aircraft and in general mechanical construction. It therefore is not concerned with the metallurgical processes to which these materials may have been previously subjected, but with their composition, strength and properties as received from the steel manufacturer and with modes of heat and other treatment. The work covers a wide range, and is intended as a reference work for designers and builders of machines.

AMERICAN RURAL HIGHWAYS.

By T. R. Agg. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 11+139 pp., front., illus., 8 x 5 in., cloth, $2.00.

This textbook was written for use in courses on rural highways given to agricultural engineers, students of agriculture and others who do not receive training along the lines of the usual course in highway engineering. It is intended to familiarize the student with the relation of highway improvement to national progress, to indicate the problems of highway administration and to set forth the usual methods of design and construction in sufficient detail to establish a clear understanding of the characteristics and serviceability of the common types of roadway surface.

APPLICATION OF DYESTUFFS TO TEXTILES, PAPER, LEATHER AND OTHER MATERIALS.

By J. Merritt Matthews. N. Y. John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1920. 16+768 pp., illus., tables, 9 x6 in., cloth, $10.00.

The present volume is an outgrowth of the author's earlier work, "Laboratory Manual of Dyeing and Textile Chemistry," but has been broadened in scope to appeal to the interest, not only of students, but of all those concerned in the application of dyestuffs. The author has endeavored to incorporate the latest knowledge of the subject. Contains an eighteen-page bibliography.

THE CERAMIC INDUSTRIES POCKET BOOK.

By Alfred B. Searle. Lond. and N. Y., Sir Isaac Pitman & Sons., Ltd., 1920. 7+267 pp., diagrams, tables, 6 x 4 in., cloth, $3.40.

Of actual pocket size, this little volume is a compilation of data that have been found of constant use to people engaged in the clay-working, glass and allied industries.

COMPRESSED AIR PLANT; THE PRODUCTION, TRANSMISSION AND USE OF COMPRESSED AIR, WITH SPECIAL REFERENCE TO MINE SERVICE.

By Robert Peele. Fourth edition, revised and enlarged. N. Y., John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1920. 23+506 pp., illus., diagrams, tables, 9 x 6 in., cloth $4.50.

This volume deals with the varied uses of compressed air in engineering, particularly in mining, tunneling, quarrying and other work involving rock excavation. A chapter on the measurement of air consumption has been added to this edition, and also information on air-lift work. Typographical errors have also been corrected.

THE COST OF MINING.

By James Ralph Finlay. Third edition, revised, enlarged and reset. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 11+532 pp., maps, tables, 9 x 6 in., cloth. $6.00.

This work was originally a study of the cost of mining the more important economic minerals, undertaken to show how the natural factors invariably impose certain costs that sound engineering must recognize, and that to attempt economies unjustified by the conditions is extravagance.

The present edition has been broadened in scope, chiefly by the insertion of generalizations on geologic history and processes that tend to explain the origin and govern the distribution of important minerals. It is less narrowly technical than its predecessors and pays more attention to those aspects of mining economics which interest the public generally.

DETAIL DESIGN OF MARINE SCREW PROPELLERS.

By Douglas H. Jackson. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. 12+92 pp., tables charts, diagrams, 9 x 6 in., cloth, $2.50.

The author feels that many works on screw-propeller design carry theoretical considerations too far for the average designer. He therefore here presents, in small compass, an outline of the accepted theories, a full treatment of the practical application of them, and a short description of the various manufacturing methods. A chapter on repair work is also included.

THE DEVELOPMENT OF INSTITUTIONS UNDER IRRIGATION, WITH SPECIAL REFERENCE TO EARLY UTAH CONDITIONS.

By George Thomas, N. Y., The Macmillan Co., 1920. 7+293 pp., front., plate, 8 x 5 in., cloth, $2.50.

Irrigation on a large scale was first practised in America by the Utah pioneers. The present book is an account of the methods that they adopted to solve successfully one phase of the problem of irrigation, the institutional one. How the expenses of irrigation works were met, and the distribution and use of water controlled, are concisely related. The history is brought down to 1919.

A DICTIONARY OF CHEMICAL TERMS.

By James F. Couch. N. Y., D. Van Nostrand Co., 1920. 4+204 pp., 7 x 5 in., cloth $2.50.

This volume is designed to serve the convenience of readers of chemical literature by providing accurate definitions for the complex terminology of this science, in convenient form. The

treatment of the terms lies between that of a standard dictionary of the English language and that of an encyclopedia.

ELECTRO-DEPOSITION OF METALS.

By George Langbein. Translated, with additions, by W. T. Brannt. Eighth edition, revised and enlarged. N. Y., H. C. Baird & Co., Inc., 1920. 12+863 pp., illus., diagrams, 9 x 6 in., cloth, $7.50.

This book is intended as a reference book and practical guide on electroplating, based upon the scientific principles underlying the art, but devoid of mathematical technicalities. The present edition has been thoroughly revised and modernized and new methods have been added wherever necessary.

ENCYCLOPEDIA OF MARINE APPLIANCES, 1920.

Compiled by Alexander McNab. Bridgeport, Conn., The McNab Company. 206 pp., illus., 12 x 9 in., cloth. $5.00.

An interesting catalog of marine appliances, made or sold by the publishers.

THE ENGINEERING DRAUGHTSMAN.

By E. Rowarth. N. Y., E. P. Dutton and Company. 24+245 pp., diagrams, tables, 9 x 6 in., cloth. $5.00.

This book, intended for those familiar with the elementary principles of engineering drawing, is a collection of ninety-six exercises arranged to illustrate the application of the principles in the production of working drawings. These examples show how working drawings of details are made from information obtained from general assembly drawings, how assembly drawings are made from detailed working drawings, how detailed working drawings are modified in shape and size, to suit new machines. The plates cover a wide range of work and are taken from drawings of commercial machines.

THE ESSENTIALS OF DESCRIPTIVE GEOMETRY.

By F. G. Higbee. Third edition, revised. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1920. 8+218 pp., diagrams, 9 x 6 in., cloth. $2.25.

In writing this text the author has endeavored to include only those portions of descriptive geometry which possess industrial utility and assist in the development of a draftsman. The present edition is like the original in essentials, but certain changes have been made, in the light of classroom experience, in order to make the book more clear to the student.

HANDBOOK OF BUILDING CONSTRUCTION

Editors-in-chief, George A. Hool and Nathan C. Johnson. First edition, first impression. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 2 vols., front., illus., diagrams, tables, 9 x 6 in., cloth, $10.00.

This has been prepared to provide the architect, engineer and builder with a reference work covering thoroughly the design and construction of the principal kinds and types of modern buildings, and their mechanical and electrical equipment. Each section is the work of a specialist, and although condensed gives the information usually needed for reference by the engineer in practise. The volumes are fully illustrated by diagrams and figures.

HIGH FREQUENCY APPARATUS; DESIGN, CONSTRUCTION AND PRACTICAL APPLICATION.

By Thomas Stanley Curtis. Second edition, revised and enlarged. N. Y., Norman W. Henley Publishing Co., 1920. 269 pp., illus.. diagrams, 8 x 5 in., cloth, $3.00.

This book is a practical non-technical text-book, intended particularly for amateurs and other experimenters, and is based on a series of papers which appeared in various popular technical magazines. This edition has been slightly enlarged.

HIGHER MECHANICS.

By Horace Lamb. Cambridge, University Press, 1920. 10+272 pp., front., diagrams, 9 x 6 in., cloth. $8.00. (Gift of the Macmillan Company).

This treatise includes three-dimensional kinematics, statics and dynamics, and may be regarded as a sequel to the author's two former treatises on statics and dynamics. The author attempts to confine his attention to matters of genuine kinematical or dynamical importance, and to avoid those of purely mathematical or historical interest. The book is designed as an introduction to the subject.

THE HUMAN MOTOR OR THE SCIENTIFIC FOUNDATION OF LABOR AND INDUSTRY.

By Jules Amar. Lond., George Routledge & Sons, Ltd., N. Y., E. P. Dutton & Co., 1920. 15+470 pp., illus, charts, diagrams, 9 x 6 in., cloth. $10.00. (Gift of E. P. Dutton & Company).

This book is a study of the human body as a motor and of the conditions that govern its effectiveness. The author has collected the physiological data which govern the efficiency of human work and has also included a brief summary of the principles of mechanics. The work of Chauveau and Taylor is discussed and criticized, and the latter's system carefully examined.

LEAD, INCLUDING LEAD PIGMENTS AND THE DESILVERISATION OF LEAD.

By J. A. Smythe. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. (Pitman's common commodities and industries) 7+120 pp., front., illus., map, 7 x 5 in., cloth, $1.00.

This is a brief, straightforward account, free from technicalities, of the various processes used from the time the lead ore is dug out of the earth until the pure metal and the pigments derived from it are put on the market. No previous knowledge of chemistry and physics is required by the reader.

THE LIFE AND WORK OF SIR WILLIAM VAN HORNE.

By Walter Vaughan. N. Y., The Century Company, 1920. 13+388 pp., ports., plates, 9 x 6 in., cloth, $5.00.

Sir William Van Horne's great achievement was the construction of the Canadian Pacific and its development into a great railroad system. To the story of this achievement the greater part of Mr. Vaughan's book is devoted, but he has also treated adequately Sir William's earlier experience in railroad operation in the United States and the various projects which occupied his later life after his retirement from the presidency of the Canadian Pacific. His personality is adequately and sincerely treated, so that the book is a human record of the man, as well as a history of a railroad.

THE MODERN ELECTROPLATER.

By Kenneth M. Coggeshall. N. Y., The Norman W. Henley Publishing Co., 1920. 276 pp., illus. charts, diagrams, tables, 8 x 5 in., $3.00.

This volume is practical in purpose. It contains a description, presented as simply as possible, of the equipment and methods for electroplating in use today.

MODERN EXPLOSIVES.

By S. I. Levy. London and N. Y., Sir Isaac Pitman & Son, Ltd., 1920. (Pitman's common commodities and industries). 9+109 pp., front., illus., 7 x 5 in., cloth, $1.00.

Upon the basis of experience gained during the war, the author of this little book gives an account for general readers of the modern explosive industry. Stress is laid on the interdependence of modern industry and the necessity of viewing all research and productive activity as a whole not only for the purpose of defense, but to insure the well-being of the community.

PAPERS ON PAINT AND VARNISH AND THE MATERIALS USED IN THEIR MANUFACTURE.

By Henry A. Gardner. Washington, D. C., 1920. 501 pp., front., ports., illus., diagrams, tables, 9 x 6 in., cloth, $10.00. (Gift of the author).

In this volume the author brings up to date the series of technical papers which he has prepared as circulars of the Educational Bureau of paint and Varnish Manufacturers Association, since January 1919. The papers cover a wide variety of practical subjects, and are intended to bring a fuller realization of the importance of surface protection and a better understanding of how to obtain and maintain it.

POLITICAL AND COMMERCIAL GEOLOGY AND THE WORLD'S MINERAL RESOURCES; a Series of Studies by Specialists.

J. E. Spurr, editor. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 9+562 pp., diagrams, tables, 9 x 6 in., cloth, $5.00.

The purpose of these studies is to shed light upon the vast importance of commercial control of raw materials by different powers, or by citizens of those powers, through invested capital. The question of domestic and foreign governmental policies

of the United States is closely involved. This volume takes up the study of the actual situation as to the distribution and ownership of mineral supplies in the world and forms almost the first contribution to the investigation of the relation of geology to industry, commerce and political economy.

THE PRACTISE OF RAILWAY SURVEYING AND PERMANENT WAY WORK.

By S. Wright Perrot and F. E. G. Badger. London, Edwin Arnold, 303 pp., diagrams, charts, tables, 9 x 6 in., cloth, $10.50. (Gift of Longmans, Green and Company).

The object aimed at is to deal with the practical side of the subject, a knowledge of surveying in general being assumed. The authors gained their experience as members of the staffs of two leading English railways and also when carrying out railway work abroad. The knowledge thus acquired of the best English practise, as well as of the methods adopted in the construction of economic railways in unexplored and undeveloped countries, has enabled them to deal with the subject from the practical point of view. Many methods are original. Little or none of the matter on permanent way has previously appeared in print.

P-W-R MANUAL.

Phila., Power-Weightman-Rosengarten Co., 1920. 7+471 pp., tables, 8 x 5 in., cloth.

This is a dictionary of chemical and pharmaceutical products, giving the formulas, percentage compositions and properties of each. A collection of tables useful to analysts and others is appended.

RAPID METHODS FOR THE CHEMICAL ANALYSIS OF SPECIAL STEELS, STEEL-MAKING ALLOYS, THEIR ORES AND GRAPHITE.

By Charles Morris Johnson. Third edition, revised and enlarged. N. Y., John Wiley & Sons, Inc., Lond., Chapman-Hall Ltd., 1920. 11+552 pp., illus., tables, 9 x 6 in., cloth, $6.00.

This collection of analytical methods, by the chief of a large steel-works laboratory, represents the results of long experience in the rapid examination of steel-works materials. Many methods are original. The present edition has been expanded to include a considerable number of new methods which have been developed since the last revision of the book.

THE STANDARD ELECTRICAL DICTIONARY.

By T. O'Conor Sloane. With additions by A. E. Watson. N. Y., The Norman W. Henley Publishing Co., 1920. 767 pp., illus., diagrams, 7 x 5 in., cloth, $5.00.

Since its appearance in 1892, this work has passed through many editions and found favor as an encyclopedia dictionary of the subject. The present edition has been revised and enlarged by the addition of a second part, 185 pages long, containing the terms, appliances and theories of modern times. Cuts and diagrams are used to elucidate the text.

STORAGE BATTERY MANUAL.

By Lucius C. Dunn. Annapolis, U. S. Naval Institute, 1920. 391 pp., illus., diagrams, 9 x 6 in., cloth, $7.00.

The book is the work of a Lieutenant Commander, U. S. Navy, and is designed for the instruction of the personnel of the navy. The text has been made as simple and practical as possible, and involved formulas and mathematical expressions have been avoided wherever possible.

STORAGE BATTERY PRACTISE.

By Robert Rankin. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 11+169 pp., diagrams, charts, 9 x 6 in., cloth, $3.10.

This is an attempt to present, in concise, readable form, an account of the manufacture, installation, properties and working of storage batteries, for the practical engineer, who is not so much concerned with the details of manufacture and theory, as with the operation and maintenance of storage batteries and the auxiliary plant. The book deals mainly with stationary batteries.

THE STORY OF THE ENGINE, FROM LEVER TO LIBERTY MOTOR.

By Wilbur F. Decker. N. Y., Charles Scribner's Sons, 1920. 20+277 pp., front., illus., 8 x 5 in., cloth, $2.50.

This book is intended for readers without any previous knowledge of the subject. Beginning with the lever, the first elementary mechanical movement, the author traces the applications of mechanical principles, the gradual development of the steam engine in its various forms, and the internal combustion engine. Numerous diagrams assist the text.

TEXT-BOOK OF THE MATERIALS OF ENGINEERING.

By Herbert T. Moore. With a chapter on concrete, by H. F. Gonnerman. Second edition, first impression. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 12+315 pp., illus., charts, tables, 9 x 6 in., cloth, $3.00.

This textbook contains a concise presentation of the physical properties of the common materials used in structures and machines, together with brief descriptions of their manufacture and fabrication. It is primarily intended for use in connection with courses on the mechanics of materials, but the author hopes that it will also be useful to draftsmen, inspectors, machinists and others who use these materials.

In this edition the chapter on concrete has been rewritten, a chapter on rubber, leather and hemp rope, and other sections have been enlarged or revised.

THEORETICAL ORGANIC CHEMISTRY.

By Julius B. Cohen. Lond. Macmillan and Co., Ltd., 1920. 15+604 pp., illus., diagrams, 7 x 5 in., cloth, $2.50.

In preparing a new textbook on this subject, the author's chief aim has been to maintain a careful balance between theory and practise. The book represents the author's lectures to his students, is equipped with class demonstrations, and endeavors to arouse the curiosity and interest of the student.

THE THERMIONIC VACUUM TUBE, AND ITS APPLICATIONS.

By H. J. Van der Bijl. First edition, N. Y., and Lond., McGraw-Hill Book Co., Inc., 1920. 19+391 pp., illus., charts, diagrams, 9 x 6 in., cloth, $5.00.

In this work the author has attempted to set forth the principles of operation of these tubes and to coordinate the more important phenomena exhibited by the passage of electrons through high vacua. The treatment has been made elementary enough for those unacquainted with the subject.

THE VENTILATION HAND BOOK.

By Charles L. Hibbard. Second edition, revised and enlarged. N. Y., The Sheet Metal Publication Co., 1920. 231 pp. illus., diagrams, 8 x 6 in., cloth, $2.50.

This book is intended to present, in convenient form, the principles of warm-air heating and ventilation, with simple methods for computing the sizes of the various parts of a system of this kind. The subject matter is arranged in the form of questions and answers, and the descriptions and mathematical data are given in very simple form.

WIRTSCHAFTLICHE VERWERTUNG DER BRENNSTOFFE.

By G. de Grahl. Zweite, neu bearbeitete auflage. Munchen and Berlin, R. Oldenburg, 1921. 8+487 pp., plates, illus., charts, diagrams, 11 x 8 in., paper M.110.

This work on the economical utilization of fuels first appeared in 1915, when the economic isolation of Germany began to be effective. The present edition has been entirely rewritten in the light of the fuel situation after the war, and is an exhaustive treatise on the utilization of the available fuel supply under present conditions.

After a description of the solid, gaseous and liquid fuels, in which their efficiencies are compared, the author discusses the processes for converting and enriching them. Gas production, by-products, nitrogen utilization are treated in detail. The subject of combustion is then taken up and an extended critical discussion of methods of firing especially for steam production, is included. Another chapter discusses heating for municipalities, waste heat utilization, etc. The concluding chapter treats of the economics of energy in general. Because of its comprehensiveness, the book will interest many engineers.

WATER PURIFICATION PLANTS AND THEIR OPERATION.

By Milton F. Stein. Second edition. N. Y. John Wiley & Sons, Inc., Lond., Chapman-Hall Ltd., 1919. 10+270 pp., illus., charts, diagrams, 9 x 6 in., cloth, $3.00.

The object of the author has been to give instruction for the operation of these plants, as concisely and simply as is consistent with reasonable completeness. In general, it has been the endeavor to give special attention to the requirements of the non-technical operator of small plants. This edition has been rewritten in part, because of changes in the technique of water bacteriology, new views as to the interpretation of bacteriological tests and the need for new details in the instruction for these tests.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—November 24, 1920. Paper: "Motors in Rubber Industry." Author: Mr. M. Berthold. Chief Engineer, Imperial Electric Company, Akron, Ohio. Attendance 23.

December 22, 1920. Paper: "Recent Developments in Transformer Application and Design." Author: Mr. L. E. Wright, General Electric Company, Cincinnati, Ohio. Attendance 23.

Baltimore.—December 17, 1920, Johns Hopkins University. Business meeting followed by illustrated lecture on "Alternating-Current Motors Having Series and Shunt Characteristics" by Mr. R. A. Jones, of the General Electric Company. Attendance 70.

Boston.—December 17, 1920, Chipman Hall, Tremont Temple. Joint meeting of Boston Sections of A. I. E. E. and A. S. M. E., and the Boston Society of Civil Engineers. Subject: "Water Power Development in New England." Speaker: Professor Harold K. Barrows; discussion by Mr. Henry I. Harriman, President of the New England Power Company, who talked particularly upon the St. Lawrence project. Attendance 350.

Chicago.—December 17, 1920. Papers: "Automatic Railway Substations" by Mr. Charles H. Jones, of the Chicago, North Shore & Milwaukee R. R.; "Economic Aspects of the Light Weight Safety Car" by Mr. H. A. Johnson, Chicago, North Shore & Milwaukee R. R., and Mr. H. L. Brown, Western Editor for *Electric Railway Journal*; "Train Operation on Urban Railways" by Mr. S. B. Way, of The Milwaukee Electric Railway & Light Company. Attendance 200.

Cincinnati.—December 21, 1920, Dayton Engineers Club, Dayton, O. Subject: "Insulation Research, a Review and a Forecast." Speaker: Mr. C. E. Skinner, of the Westinghouse Elec. & Mfg. Co. Attendance 60.

Cleveland.—December 21, 1920, Cleveland Engineering Society Club Rooms. Subject: "The Purchase and Use of Electric Motors from the Owners' Standpoint." Speaker: Mr. James Burke, of the Burke Electric Company. Attendance 92.

Denver.—December 11, 1920. In the afternoon an automobile trip was made to the Brighton Plant of the Great Western Sugar Company. The party, consisting of about fifty, was taken in charge by members of the sugar company's organization and the production of beet sugar was explained from the unloading of the beets to the sacking and storing of the sugar. This was followed by a dinner at the Metropole Hotel, where Mr. B. Hutchins, Traveling Superintendent for the Great Western Sugar Company, gave a talk on sugar.

Fort Wayne.—December 16, 1920, University Club. Subject: "Evolution of the Fort Wayne Electric Works." Speaker: Mr. J. J. Kline, of the General Electric Company. Refreshments were served. Attendance 37.

Indianapolis-Lafayette.—December 17, 1920. Chamber of Commerce. Subject: "Light and Lenses." Speaker: Mr. L. W. Bugbee, of the One-Piece Bi-Focal Lens Company, of Indianapolis. Refreshments were served. Attendance 36.

Ithaca.—December 3, 1920, Franklin Hall, Cornell University. Subject: "Electric Furnaces for Steel Production." Speaker: Mr. E. T. Moore. Attendance 135.

Los Angeles.—December 7, 1920, Chamber of Commerce. Illustrated talk on "The What and Why of Industrial Illumination." Speaker: Mr. O. L. Johnson, of the Benjamin Electric Mfg. Co. Attendance 80.

Lynn.—December 8, 1920, G. E. Hall. Subject: "Super-Power System." Speaker: Mr. W. S. Murray. Attendance 250.

December 20, 1920, G. E. Hall. Subject: "The Fundamentals of Our Economic System." Speaker: Professor Ralph E. Heilman, Dean of the Northwestern University School of Commerce, Chicago. Attendance 245.

Madison.—December 14, 1920, Engineering Building, Univ. of Wis. Paper: "Resistance Neutralization: An Application of Thermionic Amplifier Circuits" (prepared jointly by Professor Edward Bennett and Mr. L. J. Peters, of the University of Wisconsin) presented by Mr. Peters. Attendance 30.

Philadelphia.—December 13, 1920, The Bellevue Stratford Hotel. Informal dinner. Subject: "Super-Power System." Speaker: Mr. William S. Murray. Attendance 558.

Pittsburgh.—December 14, 1920, Chamber of Commerce. Subject: "A Transition Period in Radio Communication." Speaker: Mr. Arthur F. Van Dyck, of the Radio Corporation of America. Attendance 200.

Pittsfield. December 2, Masonic Temple. Subject: "The Foremost Civilization of America." Speaker: Mr. Sylvanus G. Morley, Carnegie Institute. Attendance 400.

December 16, 1920, Boys' Club. Subject: "Some Ice Problems and Their Solutions." Speaker: Mr. John Murphy, Electrical Engineer of the Department of Railway and Canals, Canadian Government. Attendance 250.

January 6, 1921, Park Club. Subject: "Industrial Reconstruction in France and Belgium." Speaker: Major O. F. Allen. Attendance 230.

Portland.—December 14, 1920, University Club. Papers presented, "Contracting" by R. C. Kenney; "Accounting" by Mr. McCoy; "Fixtures" by J. C. English; "Merchandising" by C. P. Scott. Meeting was held under the auspices of the Contractors-Dealers Association. Attendance 100.

St. Louis.—December 17, 1920, American Annex Hotel. Election of officers as follows: Chairman, Mr. J. L. Woodress; Secretary-Treasurer, Mr. Walter H. Millan. Paper presented: "Automatic Substations." Speaker: Mr. R. J. Wensley, of the Westinghouse Company. Attendance 109.

San Francisco.—December 17, 1920, Engineers Club. Paper: "Electric Design and Utilization in Pacific Coast Industries." Speaker: Mr. L. F. Leurey. Attendance 45.

Schenectady.—December 17, 1920, Edison Club Hall. Subject: "Industrial Reconstruction in France and Belgium." Speaker: Major O. F. Allen. Attendance 250.

January 7, 1921, Edison Club Hall. Subject: "The Manufacture and Use of Die Castings." Speaker: Mr. Chas. Pack, Chief Chemist Doehler Die Casting Company of Brooklyn, N. Y. Attendance 175.

Seattle.—December 21, 1920, Arctic Club Assembly. Business meeting, followed by discussion of Mr. Ross' paper as presented at the November meeting. Attendance 65.

Spokane.—December 18, 1920, Davenport Hotel. Subject: "Wireless Telegraphy and Telephony." Speaker: Mr. E. V. Olson, of the Washington Water Power Co. Attendance 98.

Syracuse.—December 10, 1920, Technology Club. Subject: "Where Syracuse Gets Power." Speaker: Mr. W. C. Pearce. Attendance 72.

Toronto.—December 10, 1920, University of Toronto. Paper: "Submarine Detection in an Alternating Magnetic Field." Author: Dr. John B. Whitehead, John Hopkins University. Attendance 83.

December 22, 1920, University of Toronto. Joint meeting of the Toronto Section of the A. I. E. E. and The Royal Canadian Institute. Subject: "The Twentieth Century's Contribution to our Knowledge of the Atom." Speaker: Dr. R. A. Millikan, of the University of Chicago. Attendance 416.

Urbana.—December 17, 1920. Subjects: "Opportunities with the Westinghouse Company" by Mr. P. A. Burkhardt; "Recent Developments in Radio Engineering" by Mr. H. A. Brown. Attendance 60.

Utah.—December 11, 1920, Commercial Club. Paper: "Habits of the Electron" (illustrated with slides). Author: Dr. Saul Dushman. Attendance 65.

Washington.—December 14, 1920, Cosmos Club Hall. Mr. R. E. Wooley, Manager of the Flow Meter Department of the G. E. Co., delivered an illustrated address on the description and principles of flow meters of various makes, the use of these instruments on boilers and in steam lines for industrial purposes, heating, etc. Refreshments were served. Attendance 124.

Worcester.—January 4, 1921, Worcester Polytechnic Institute. Subject: "Power Transmission." Speaker: Mr. E. W. Pragst, Power and Mining Department, General Electric Company. Attendance 103.

PAST BRANCH MEETINGS

Brooklyn Polytechnic Institute.—December 9, 1920. Subject: "History and Development of the Telephone." Speaker: Mr. Howard W. Mott, of the Western Electric Company. Attendance 30.

Carnegie Institute of Technology.—December 7, 1920. Subjects: "Merchandising of Electrical Equipment" by Mr. Clarke, Sales Dept., Westinghouse Elec. & Mfg. Co. "Publicity and Trade Promotion" by Mr. Waxman, Sales Dept., Westinghouse Elec. & Mfg. Co. Attendance 31.

Case School of Applied Science.—December 14, 1920. A talk was given by Mr. C. C. Dash, of the Hertner Electric Company, Cleveland, on the Application of Motor Generator Sets to Motion Picture Projection. Attendance 41.

University of Cincinnati.—November 23, 1920. Illustrated talk on "Some Special Features of the New Dixie Terminal Buildings of Cincinnati" by Mr. C. F. Fosdick, engineer with Walter Frantz. Attendance 92.

November 30, 1920. Subject: "Public Utilization and the Growth of the Power Company in Cincinnati." Speaker: Mr. W. W. Freeman, President of the Union Gas & Elec. Co. of Cincinnati. Attendance 68.

December 7, 1920. Mr. C. F. Fosdick repeated his talk of November 23, on "Some Special Features of the New Dixie Terminal Buildings of Cincinnati." Attendance 50.

Clemson College.—January 11, 1921. Debate: "Steam Locomotives versus Electric Locomotives." Steam—Messrs. Hoffmeyer and Tyler; Electric—Messrs. Watkins and Readen. Debate was won by the advocates of the steam locomotive. Current events were given by H. W. Hood. Attendance 42.

University of Colorado.—December 2, 1920. Talk by Mr. R. Prout, of the Western Union Telegraph Co. of Denver, on "Multiplex Telegraph System." Attendance 38.

University of Iowa.—December 6, 1920. Subjects: "Air Craft Radio" by M. Carlson, and "The New Niagara Power Project" by H. E. Hood. Attendance 31.

December 13, 1920. Subjects: "The Incandescent Lamp" by R. Klatt, and "Thawing of Water Pipes by Electricity" by A. P. Byers. Attendance 34.

University of Kansas.—December 12, 1920, Fraser Hall. The following moving pictures were shown: "The Benefactor," "The Electric Giant," "The Potters Wheel," and "The Land of Cotton." Attendance 50.

University of Kentucky.—December 13, 1920, Mechanical Hall. Subjects: "Oscillators on Electrical Machinery" (taken from Power) by E. O. Shultz, and "Lightning Arresters" by B. Thornton. Attendance 22.

University of Maine.—December 8, 1920, Lord Hall. Mr. W. A. Taylor talked of his work during the summer with the General Electric Company, and Mr. W. J. Creamer outlined his work with the Western Electric Company during the war on the development of the "sea-phone" used for detection of submarines. Attendance 22.

Massachusetts Institute of Technology. January 12, 1921. Subject: "The Story of the Telephone." Speaker: Mr. W. H. Freedman, of the A. T. & T. Co., New York. Refreshments were served. Attendance 92.

University of Minnesota.—December 20, 1920. Subjects: "The Signal Corps in The World War" by Major Ingles; "The Joint Engineering Board" by Professor G. D. Shepardson. Attendance 37.

University of Notre Dame.—December 6, 1920. Election of officers as follows: Chairman, Frank Miles; Vice-Chairman, D. Fitzgerald; Secretary, W. Shiltz; Treasurer, J. Huether. Attendance 21.

December 17, 1920. Subject: "What is Electricity?" Speaker: Dean Fitzgerald. Attendance 16.

Ohio Northern University.—December 20, 1920. Subjects: "The Colfax Power Station" by Howard D. Ronk; "The 150,000-Volt Transmission Line of the Knoxville Power Co." by F. W. Beyer (this article taken from JOURNAL, by Theodore Varney). Attendance 13.

Ohio State University.—December 16, 1920. Business meeting, followed by a social period and talk by Y. T. Yang, a Senior from China, on "The Achievements of Engineering in China." Attendance 25.

University of Oklahoma.—December 9, 1920. Moving picture "The King of the Rails" was shown. Attendance 163.

Oregon State Agricultural College.—December 15, 1920. Moving picture "The Land of Cotton" was shown. Attendance 15.

University of Pennsylvania.—December 7, 1920. Subject: "Lighting of Buildings." Speaker: Mr. D. Albertson. Attendance 48.

December 14, 1920. Subject "Telephone Cables." Speaker Mr. G. C. Eldridge. Attendance 48.

January 4, 1920. Subject: "Power Requirements of Telephone Central Offices." Speaker: Mr. J. F. Haines. Attendance 48.

Purdue University.—December 14, 1920. Joint meeting of the Purdue Branches of A. I. E. E., A. S. M. E. and Civil Engineering Society. Subject: "Design, Construction and Operation of Water Turbines." Speaker: Mr. D. J. McCormack, Hydraulic Engineer for the Wellman, Seaver, Morgan Co. Attendance 189.

Rose Polytechnic Institute.—December 15, 1920. Subject: "Electric Arc Welding Processes and Application." Speaker: Mr. W. W. Reddie, of the Westinghouse Elec. & Mfg. Co. Attendance 163.

University of Texas.—January 10, 1921. Talks by Messrs. Bantel and Bryant. Moving picture "The Benefactor" was shown. Attendance 310.

University of Virginia.—December 2, 1920. Demonstrated lecture on "Audion Bulbs" by Professor L. G. Hoxton. Attendance 40.

University of Washington.—December 7, 1920. Mr. A. Kalin, a member of the E. E. faculty, gave a talk on the school of instruction of the Westinghouse Company with whom he has been for the last year. Attendance 28.

Washington State College.—December 10, 1920. Subject: "The Successful Man." Speaker: Professor M. K. Synder. Attendance 22.

West Virginia University.—December 13, 1920. The following papers were read: "Electric Safety Lamps," by H. S. Shinn; "Suspension Insulators," by H. Chandler; "Mercury Vapor Lamps," by A. C. Price; "Measurement of Projectile Velocities," by J. L. Hark; "Advantages of Electric Drive for Battleships," by C. M. Hill. Attendance 13.

January 10, 1921. The following papers were read: "Wireless Telephony," by R. D. Brown; "Factory Lighting," by H. Chandler; "Some A. I. E. E. Meetings I have Attended," by H. M. McLain. Attendance 14.

Yale University.—December 14, 1920. Subject: "Joint Use of Overhead Lines—Telephone and Power." Speaker: Mr. T. N. Bradshaw, Outside Engineer of Southern New England Telephone Company. Attendance 49.

ENGINEERING SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

SERVICES AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after an interval of three months, during this period names and records will remain in the active files.

NOTE.—All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to the ENGINEERING SOCIETIES EMPLOYMENT BUREAU, 33 West 39th Street, New York City, the employment clearing house of the National Societies of Civil, Mining, Mechanical and Electrical Engineers.

OPPORTUNITIES

To assist in the conduct of engineering research and to extend and strengthen the field of its graduate work in engineering, the University of Illinois maintains fourteen Research Graduate Assistantships in the Engineering Experiment Station. Two other such assistantships have been established under the patronage of the Illinois Gas Association. These assistantships, for each of which there is an annual stipend of $600 and freedom from all fees except the matriculation and diploma fees, are open to graduates of approved American and foreign universities and technical schools who are prepared to undertake graduate study in engineering, physics, or applied chemistry.

An appointment to the position of Research Graduate Assistant is made and must be accepted for two consecutive collegiate years, at the expiration of which period, if all requirements have been met, the degree of Master of Science will be conferred. Not more than half of the time of a Research Graduate Assistant is required in connection with the work of the department to which he is assigned, the remainder being available for graduate study.

Nominations to these positions, accompanied by assignments to special departments of the Engineering Experiment Station, are made from applications received by the Director of the Station each year not later than the first day of March. The nominations are made by the Executive Staff of the Station, subject to the approval of the President of the University. Nominations are based upon the character, scholastic attainments, and promise of success in the principal line of study or research to which the candidate proposes to devote himself. Preference is given those applicants who have had some practical engineering experience following the completion of their undergraduate work. Appointments are made in the spring, and they become effective the first day of the following September. Vacancies may be filled by similar nominations and appointments at other times.

The Engineering Experiment Station, an organization within the College of Engineering, was established in 1903 for the purpose of conducting investigations in the various branches of engineering, and for the study of problems of importance to engineers and to the manufacturing and industrial interests of the State of Illinois. Research work and graduate study may be undertaken in architecture, architectural engineering, ceramic engineering, chemistry, civil engineering, electrical engineering, mechanical engineering, mining engineering, municipal and sanitary engineering, physics, railway engineering, and theoretical and applied mechanics.

The work of the Engineering Experiment Station is closely related to that of the College of Engineering, and the Heads of Departments in the College constitute the Executive Staff of the Station. Investigations are carried on by members of the Station staff and also by members of the instructional staff of the College of Engineering.

Additional information may be obtained by addressing

THE DIRECTOR,
Engineering Experiment Station,
University of Illinois,
Urbana, Illinois.

SEVERAL RECENT TECHNICAL GRADUATES wanted by central station in East. Applicants to start in various departments of the Company and will be promoted as they gain experience. Give education, any experience and salary expected at start. Z-2643.

YOUNG MAN WITH TECHNICAL EDUCATION and experience in the design, construction and operation of 2200 volt or standard city distribution lines. Reply giving education, experience, references and salary expected. Z-2644.

SALES ENGINEER. Must be a technical graduate with E. E. degree. between 22-35 years old. Some sales, testing and, repairing experience in small motors desirable. Location New York City. Z-2648.

ELECTRICAL DRAFTSMAN. Experienced in substation design, conduit and switchboard layout. State age, experience, education and salary expected. Location Wisconsin. X-19.

ASSISTANT PHYSICIST for research work with government. X-60.

YOUNG ELECTRICAL ENGINEER with some experience in development, teaching, test, radio or laboratory, as Junior in development laboratory for automotive equipment. Unusual opportunity for a man of good fundamental training and proper personal qualifications. Location Mass. X-46.

YOUNG MAN, age 25; married; partial technical training. Five years electrical experience on actual construction, engineering and drafting, designing of power plants and substations, switchboards and general electrical installations. Desires position with prospects for advancement. Location Philadelphia or near by. Available immediately. E-2491.

ELECTRICAL ENGINEER, available immediately for purchasing, sales or responsible engineering position. Six years broad electrical experience. G. E. test, development work, public utility, maintenance, refrigeration; 1½ years export; excellent grasp of mechanical engineering. Degree E. E., Columbia. Age 29, married. Associate A. I. E. E. Willing to travel. Energetic, capable, good personality. Best references. E-2492.

COMBUSTION ENGINEER, desires connection with fuel burning power plant. Has available methods of reducing fuel costs by one dollar per ton, and also of substantially increasing boiler ratings. E-2493.

ELECTRICAL MECHANICAL ENGINEER, A. I. E. E., age 42; married, university graduate. Fifteen years experience in design and construction of power and substations, electrical machinery and equipment, and industrial engineering. Thoroughly conversant with a. c. and d. c. systems and distribution, high and low tension in U. S. A. and abroad. E-2494.

PHYSICIST ELECTRICAL ENGINEER, age 31; married. Member A. I. E. E. and American Physical Society. College graduate. Practical, executive and teaching experience in electrical engineering and physics. Available on reasonable notice. Can give references and particulars to those interested. E-2495.

ELECTRICAL FOREMAN, I. C. S. graduate. Seven years experience with construction, industrial and operating companies, desires responsible position with power company. Interested in electrical calculation and design. Age 23; married. Assoc. A. I. E. E. E-2496.

ASSISTANT TO EXECUTIVE. Young man, age 26, in firm where there is advancement. Have had electrical engineering education. First class references. Past five years with large public utility in maintenance department. Also have experience in accounting office of steamship company. Available on short notice. E-2497.

ELECTRICAL ENGINEER, technical graduate. Seventeen years experience in industrial and public utility work. Thoroughly capable and experienced in design and operation of high-tension transmission and distribution problems, also organization and supervision of meter work, underground and submarine cable systems to 22,000 volts, steam turbine and power house equipment. Desires permanent position with large industrial or public utility where there is chance for advancement. E-2498.

EXECUTIVE ENGINEER. Capable of taking charge of development of electrical and mechanical apparatus or position as factory manager or superintendent. Age 35; thirteen years experience. E-2499.

PRODUCTION MANAGER. I have prepared a booklet describing myself, and it will be sent on request to any manufacturer of electrical, mechanical or technical apparatus, who wants a man to take charge of manufacture. E-2500.

INDUSTRIAL ELECTRICIAN AND ENGINEER, I. C. S. graduate, age 35; married. Sixteen years experience in factory electrification, power generation, distribution, motor application, illumination, power plant, substation switchboard, automatic control, wiring maintenance and design, winding, assembling, testfloor, and laboratory experience. Reference past employers, desires position leading to permanency with industrial or operating company in U. S. E-2501.

SALES ENGINEER. Technical education; twelve years experience; motors and control, electric traveling cranes or similar equipment. Age 31. Location desired New York City. Salary $4000. E-2502.

ELECTRICAL ENGINEER, age 33, university graduate. Ten years experience in designing, distribution and construction of power plants, substations and transmission lines, desires permanent position with large company. Salary $200.00 monthly. E-2503.

BATTERY AND ELECTRICAL ENGINEER, Assoc. A. I. E. E. technical training, age 33; seven years submarine battery experience; exceptional experience in marine electrical installation; two years as superintendent of electrical shop U. S. Navy Yard; five years executive experience, familiar with all makes of storage batteries. E-2504.

GRADUATE ELECTRICAL ENGINEER, age 28. Five years experience in factory and office including three years G. E. test and two years general engineering work, such as investigations and reports on power and transmission problems, use of calculating table, power rates, etc. At present acting as technical advisor to chief engineer of large hydroelectric system. Desires position of greater responsibility and broader opportunities with hydroelectric company or for firm of consulting engineers. Salary $2500 to start. E-2505.

ENGINEERING EXECUTIVE, university graduate, G. E. test. Ten years experience in steam railway electrification, seven years in charge of development work with two manufacturing concerns. Excellent record. E-2506.

SALES ENGINEER, desirous of operating a number of carefully selected high grade non-interfering accounts in the vicinity of New York and for export to foreign countries. Fifteen years experience in professional and commercial engineering work. Successfully introduced a number of products and with existing organization in the position to quickly penetrate the trade with several new lines. E-2507.

ELECTRICAL POWER PLANT DESIGNER and field engineer, also experienced in maintenance and operation of central stations. University graduate with G. E. Test and four years electrical experience including layout and installation of transmission lines and underground distribution systems. Capable, energetic and resourceful. Present connection too limited. Age 30. Available ten days. Position desired in middle west. E-2508.

ELECTRICAL ENGINEER and assistant manager for Gas & Electric company serving territory of 50,000 population, desirous of employment with utility serving larger territory, or as manager of smaller utility. Twelve years experience in utility fields. E-2509.

WANTED position on the technical staff of a financial underwriting or analytical organization to investigate scientific technical and commercial soundness of industrial, public utility and other enterprises. Six years engineering experience. Large acquaintance among engineers. Member A. I. E. E. and A. S. M. E. Salary $6000 per year. E-2510.

ELECTRICAL ENGINEER, seven years on manufacture test, maintenance and construction of electrical apparatus including telephones, thermoelectric apparatus, meters, a. c. and d. c. motors and generators, synchronous converters, transformers, electric furnaces both for melting and heat treating purposes, power plant equipment, a. c. and d. c. motor control apparatus, etc. Have trained myself technically by studying during spare time as I progessed with my work. Am at present employed as construction foreman for large electrical manufacturing concern on complaint work. Available 30 days notice. Minimum salary $2500. E-2511.

INDUSTRIAL ELECTRICAL ENGINEER, 10 years experience in design, construction and operation of steel and industrial plants. Capable of assuming responsible charge of work. Married. Available immediately. E-2512.

ELECTRICAL ENGINEER, 1917 Illinois Electrical Engineering graduate, age 28, sound business training; six years of railway, power, shop and distribution experience. Salary $200.00 per month. E-2513.

GRADUATE ELECTRICAL ENGINEER, age 26. Three years electrical and mechanical engineering and test experience in large turbo-electric station, during which time handled correspondence concerning orders, etc. Desires position with firm of consulting engineers in connection with power plant design. At present employed; available on short notice. E-2514.

ELECTRICAL ENGINEER, technically trained, nine years practical experience station operation, electrical plant maintenance, design and improvement. Wide experience as draftsman with large textile manufacturer on factory electrification. Well qualified to design complete mill power and lighting installations. Expert industrial illumination. Age 30, married, excellent references. Associate A. I. E. E. Available February. E-2515.

ENGINEER-EXECUTIVE, desires semi-engineering, semi-commercial position. Now in charge manufacturing plant. Thorough knowledge Mexican conditions, political, commercial, geographical. Experienced in English and Spanish correspondence and translation; office management, oil prospecting, mapping, factory construction. Knowledge of French and German. E-2516.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER, Member A. I. E.E. Age 35; married. Six years assistant general manager of electrical construction company. Two years electrical officer in Navy; two years in sales department of manufacturing company. Desires permanent position in sales or administrative end of industrial concern. Opportunity for advancement of primary, and salary at beginning of secondary consideration. Location preferred East Coast. Available 30 to 60 days. E-2481.

INDUSTRIAL PLANT ELECTRICAL ENGINEER; graduate; age 30; speaks Spanish. Nine years experience in design, selection and ordering of material, construction and operation of electrical power and industrial equipment of large installations. Prefers proposition based on results attained. Seeks position offering great enough opportunities to warrant permanent residence. E-2482.

GRADUATE ELECTRICAL ENGINEER with two years experience in telephone field desires foreign service. Preferably in China or Japan, where telephone experience and knowledge of radio will be a decided asset. Age 24. E-2483.

YOUNG ELECTRICAL ENGINEER (1919) age 23, Spanish native tongue, with some technical and commercial experience, desires a position in Philadelphia. Willing to start at the bottom where there are good prospects of advancement. E-2484.

YOUNG MAN, engineer graduate (1919) desires position with electrical contractor, or as assistant engineer in industrial plant on maintenance work. Familar with work mentioned. E-2485.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, age 32. Ten years experience both practical and executive, in the construction, operation, purchasing and management of a steel mill, power station and export propositions. Available on short notice. New York district preferred. Present salary $5000. E-2486.

ENGINEERING EXECUTIVE. Graduate electrical engineer. Extensive experience in construction, and operation of electric railways and power properties, also metal working factory management and syndicate work. Like opportunity, or with consulting construction or sales organization desired. Minimum basis $5000. Prefer less fixed amount with share or bonus proportionate to results. E-2487.

Graduate Electrical Engineer desires position with progressive business concern which will afford opportunity for advancement. One year designing and manufacturing automobile transformer coils. Ex-Army officer, energetic, amiable and dependable. E-2488.

Public Utility Engineer, superintendent or manager, experienced in design construction and management of gas and electric plants, long distance transmission systems, railways, etc., twelve years technical engineering and construction; six years operating management. Expert at rate making and experienced in handling municipal councils and state commission problems. E-2489.

Development Engineer. University graduate in electrical engineering 1919. Experience in development and supervisory work on manufacturing processes for large electrical manufacturing concern. Capable of taking responsibility of new developments where principles of physics must be practically applied. Middle western location preferred. E-2490.

AMERICAN SOCIETY OF LUBRICATION ENGINEERS

The American Society of Lubrication Engineers was organized September 22, 1920, at a meeting of engineers from the petroleum industry, the automotive industry and the oil equipment industry. The purpose of the Society as stated in the charter, is—

"To promote a better understanding of the problems of lubrication and the use of liquid fuels, including all problems of application and conservation."

The Society was granted a charter by the State of Illinois and a Constitution and By-Laws adopted. An official organ entitled *Scientific Lubrication* will be published and those members of the Institute interested may obtain a copy of the January number and other information by writing G. E. Fuller, Secretary, American Society of Lubrication Engineers, Monadnock Block, Chicago, Ill.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of anyof these members is requested to communicate with the Secretary, 33 West 39th Street.

1.—Leo Arany, Room 201 Parkway Bldg., Broad & Cherry St. Philadelphia, Pa.

2.—De Los De Tar, 411 East 15th St., Kansas City, Mo.

3.—Elliott, Electric Controller & Mfg. Co., Oliver Bldg., Pittsburgh, Pa.

4.—Alex. E. Kieth, 138 Elm Street, Hinsdale, Ill.

5.—H. S. Logan, 215-15th Street, Seattle, Wash.

6.—Leonard Morey, 1067 East 153rd St., Cleveland, Ohio.

7.—P. J. Reese, 7th & Main Street, Royal Oak, Mibh.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 14, 1921

Aabye, Jorgen, Danish Consulate, 8 Bridge St., New York, N. Y.

Abbett, Hugh Wheeler, Engineer, Public Service Comm. of Indiana, State House, Indianapolis; res., Oaklandon, Ind.

Adams, Frederic O., Works Supt., Lancashire Dynamo & Motor Co., Ltd., 45 Niagara St., Toronto, Ont., Can.

Anderson, Arthur H., 1811 Sixth Ave., Watervliet, N. Y.

Araujo, Cauby, Chief Engineer, Mayrink Veiga & Co., Rua Municipal 21, Rio de Janeiro, Brazil, S. A.

Armstrong, H. Vernon, Asst. Chief Draftsman, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

Bagnall, George E., Draftsman, The Detroit Edison Co.; res., 2181 Eastlawn Ave., Detroit, Mich.

Baker, Clark E., Electrical Engineer, Railway & Traction Engineering Dept., General Electric Co., Schenectady, N. Y.

Beach, Earl L., Primary Inspector, Detroit Edison Co.; res., 914 Lawndale Ave., Detroit, Mich.

Beck, Chas. J., Draughtsman, Elec. Dept., N. Y. Shipbuilding Corp., Camden, N. J.; res., 5829 Florence Ave., Philadelphia, Pa.

Benson, Henry W., Student Electrical Engineer, General Electric Co., Lynn; res., 6 Boston Ave., Somerville, Mass.

Beymer, Oliver H., Transformer Commercial Dept., General Electric Co.; res., 33 Edward Ave., Pittsfield, Mass.

Bisbee, Frederick C., Engineering Asst., Bell Telephone Company of Pennsylvania, 1631 Arch St., Philadelphia, Pa.

Blanton, Burt C., Mechanical Engineer, 406 Sumpter Bldg., Dallas, Texas.

Boruch, Edwin R., Student Engineer, Testing Dept., General Electric Co.; res., 67 Hull Ave., Pittsfield, Mass.

Carraway, Thomas W., Chief Engineer, U. S. Government Repair Unit No. 304, Camp Normoyle, Texas.

Conroy, Francis D., Electrical Draughtsman, Stone & Webster, Inc., 147 Milk St., Boston, Mass.

Cook, Querin H., Member of Firm of Meyer & Cook, 30 N. Dearborn St., Chicago, Ill.

Cox, Harold N., Draftsman, Ewart, Jacob & Byam, Ltd., 207 Excelsior Life Bldg., Toronto, Ont.

Cross, Samuel A., Asst. Electrical Inspector, N. Y., N. H. & H. R. R. Co., Van Nest; res., 420 E. 141st St., New York, N. Y.

Culligan, Michael, Asst. Transmission Engineer, Hydro-Electric Power Commission, Toronto; res., Port Credit, Ont., Can.

Dalas, Frank L., Chief Electrician, Cia. De Santa Gertrudis, S. A., Pachuca, Hidalgo, Mexico.

Dane, Francis W., Engineer in charge, Luthy Battery Sales Company of New England, Boston; res., Main St., Hamilton, Mass.

Danner, Roy, Chief Electrician, Wadsworth Mfg. Co., Detroit, Mich.

de Castillo, Edmond R., General Tester, New York Edison Co.; res., Hotel Endicott, West 81st St., New York, N. Y.

Dolen, David O., Power House Operator, Libby Water & Electric Co., Libby, Mont.

Droege, Harry G., Supervisor of Power & Lighting, Michigan State Telephone Co.; res., 69 Brown Place, Detroit, Mich.

Edmonds, Montrose, Quotation Clerk, General Electric Co., 1000 Lexington Bldg., Baltimore, Md.

Elwell, John M., Special Inspector, Philadelphia Electric Co.; res., 5321 Walnut St., Philadelphia, Pa.

Fairlie, Howard W., Sales Manager, Monarch Electric Co. Ltd., St. Lambert, District of Montreal, Can.

Feder, Tobias M., Research Engineer, Jeffery-Dewitt Insulator Co., Kenova, W. Va.

Fisher, Victor R., Chief Radio Electrician, U. S. Naval Radio Station, Balboa, C. Z.

*Frampton, Arthur H., Laboratory Asst., Hydro-Electric Power Commission, 8 Strachan Ave., Toronto, Ont., Canada.

Frey, George F., Engineering Dept., Western Electric Co., 463 West St., New York; res., Bayside, N. Y.

Furr, Guy L., Engineer, Appalachian Power Co., Bluefield, W. Va.

Galbraith, A. R., Draftsman, Hydro-Electric Power Commission of Ontario; res., 180 Cottingham St., Toronto, Ont., Canada.

Gifford, Frederic A., Student Electrical Engineer, General

Electric Co., W. Lynn; res., 25 Lawrence St., Woburn, Mass.

GLADWELL, REGINALD R., Student Engineer, Test Course, General Electric Co.; res., 618 Chapel St., Schenectady, N. Y.

*GOODALE, JOHN C., Engineer, Fairbanks, Morse & Co., 333 E. Huron St., Ann Arbor, Mich.

GOODWIN, HAROLD L., Rawson Electrical Instrument Co.' 4 Norfolk St., Cambridge, Mass.

GOULD, WILLIAM T., Load Dispatcher, Edison Electric Ill. Co. of Boston, So. Boston; res., 638 Metropolitan Ave., Hyde Park, Mass.

GRAU, WILLIAM F., Sales Engineer, Lincoln Electric Co., 810 Mercantile Library Bldg., Cincinnati, Ohio.

HACKBUSCH, RALPH A., Asst. to District Engineer, Canadian Westinghouse Co., 366 Adelaide St. W., Toronto, Ont.

HAESLER, GEORGE M., Electrical Draftman, L. K. Comstock & Co., 21 E. 40th St., New York; res., 8752 Lefferts Ave., Richmond Hill, N. Y.

HANNON, JOHN W., Division Plant Supt., Indiana Bell Telephone Co., 212 W. Colfax, South Bend, Indiana.

HANSEL, FLOYD M., Transformer Designing Engineer, General Electric Co.; res., 1203 W. Jefferson St., Ft. Wayne, Ind.

HARRISON, S. HENRY, Asst. Works Manager, Vulcanite Portland Cement Co.; res., 318 Parsons St., Easton, Pa.

HAYBALL, WALTER, Asst. Elec. Supervisor, Michigan Central R. R.; res., 3735 Bushey St., Detroit, Mich.

HEAL, FREDERICK H., Garage, Rua Marques de Abrantes 102, Rio de Janeiro, Brazil, S. A.

HEFNER, GEORGE R., Electrical Engineer, Robert Gair Co., 50 Washington St.; res., 1333 E. 24th St., Brooklyn, N. Y.

HERLITZ, IVAR, Electrical Engineer, Stipendiate of the Am. Scandinavian Foundation; res., 63 Wendell St., Cambridge, Mass.

HODTUM, JOSEPH B., Engineer, The Union Gas & Electric Co., Cincinnati, Ohio.

INNES, WILLIAM A., Station Engineer, Addington Substation, Lake Coleridge Power Plant, Christchurch, N. Z.

JORDAN, LEE J., Salesman, Northern Electric Co., 131 Simcoe St., Toronto, Ont., Canada.

KANE, THOMAS L., Jr., Electrical Salesman, Publicity Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 536 Trenton Ave., Wilkinsburg, Pa.

KIPP, LOUIS H., Electrician, Southwest Cotton Co., Phoenix, Ariz.

KNIGHT, FRANK M., Electrical Draftsman, Albert C. Wood, Stock Exchange Bldg., Philadelphia; res., W. Philadelphia, Pa.

KOCH, CARL J., Instruction Supervisor, Ext. Division, School of Engg. of Milwaukee; res., 645 Cass St., Milwaukee, Wis.

LARSON, HERMAN R., Dynamo Test Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 224 Emerson St., E. Liberty, Pittsburgh, Pa.

LEATH, OLIVER M., Industrial Sales Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 736 Rebecca Ave., Wilkinsburg, Pa.

LOCKROW, LAURICE L., Instructor in Physics, The Rice Institute, Houston, Texas.

LUNDSTROM, AXEL W., Engineer, Sprague Electric Works, Maspeth, L. I.; res., 6 West 102nd St., New York, N. Y.

LYNCH, JOHN T., Factory Engineer, The Wagner Electrical Mfg. Co.; res., 6157 Gambleton Ave., St. Louis, Mo.

MAIERS, MATTHIAS J., Instructor, Electrical Engineering Laboratory, School of Engineering of Milwaukee; res., 645 Cass St., Milwaukee, Wis.

MALONEY, PHILIP R., Junior Electrical Engineer, Dept. of Gas & Electricity, City of Chicago; res., 6948 S. Lincoln St., Chicago, Ill.

MARTIN, WILLIAM R., Electrician, New York, New Haven & Hartford Railroad Co., New London; res., Fairview Ave., Groton, Conn.

MCGUINNESS, JOHN L., Salesman, Electric Storage Battery Co., 23 W. 43rd St., New York, N. Y.

MCLEAN, ALLAN, Plant Dept., American Tel. & Tel. Co., 172 Fulton St., New York; res., 55 Hanson Place, Brooklyn, N. Y.

MINSHULL, GEORGE R., Central Office Inspector, Michigan State Telephone Co., Bell Telephone Bldg., 185 Cass Ave., Detroit, Mich.

MIYAHARA, NOBUHIDE, Electrical Engineer, Tabota Substation Inawashiro Hydro-Electric Power Co., Ugo; res., 52 Sendagicho, Hongo, Tokio, Japan.

MORASH, JAMES R., Sales Engineer, General Electric Co., Monadnock Bldg., Chicago, Ill.

MORRILL, LEROY B., Student Engineer, General Electric Co., W. Lynn; res., 19 Irving St., Malden, Mass.

MUEHLBERGER, GEORGE C., Supervisor, Crown Cork & Seal Co., Highlandtown; res., 1810 Light St., Baltimore, Md.

NORMAN, FREDERICK E., Sales Engineer, Hubbard & Co., 50 Church St., New York, N. Y.

O'BANION, ALBERT L., Manufacturing Engineer, General Electric Co., Bridgeport, Conn.

OBATA, MANKICHIRO, Research Engineer; res., 103 Centre St., Brooklyn, Mass.

OWEN, CASPER L., Plant Dept., American Tel. & Tel. Co., New York; res., 55 Hanson Place, Brooklyn, N. Y.

PARISIAN, GURDEN R., District Wire Chief, Michigan State Telephone Co., 20 Clifford St., Detroit, Mich.

PARKS, ROBERT C., Industrial Engineer, Century Electric Co., 10 High St., Boston, Mass.

PATERSON, ELLSWORTH G. D., 1815 Seventh Ave., New York, N. Y.

PFEIFFER, C. L., Valuation Work, Oklahoma Gas & Electric Co., Oklahoma City, Okla.; res., 124 W. 113th Place, Chicago, Ill.

PROTHEROE, RODERICK N. L., Asst. Electrical Engineer, St. John del Rey Mining Co. Ltd., Morro Velho, Villa Nova de Lima, Minas, Brazil, S. A.

REID, RUSSELL E., Central Office Inspector, Michigan State Telephone Co., 185 Cass Ave., Detroit, Mich.

SCHLESINGER, OSCAR A., Power Apparatus Specialist, Western Electric Co., San Francisco; res., 64 Fairview Ave., Piedmont, Cal.

SCHRANTZ, JAMES W., Sales Engineer, Westinghouse Elec. & Mfg. Co., 1100 Traction Bldg., Cincinnati, Ohio.

SIEGFRIED, AUGUSTUS H., Chief Electrician, Los Angeles Co. Farm, Hondo, Los Angeles County, Cal.

SILLSTROP, JOHN P., Asst. Supt of Construction, The Maintenance Co., 417-421 Canal St.; res., 634 Bergen Ave., New York, N. Y.

SINCLAIR, WILLIAM J., Electrical Engineer & Contractor, Gisborne, N. Z.

SMITH, ARTHUR, Director of Physics, Central Technical School, Toronto, Ont., Can.

STAINES, GEORGE, Electrical Draughtsman, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont.

STANFORD, ALAN G., Electrical Engineer, Robert & Co., Red Cross Bldg., Atlanta, Ga.

STEVENS, GEORGE C., Electrical Engineer, Messrs. Walter & Co., 65 Rua General Camara, Rio de Janeiro, Brazil, S. A.

STEVERS, HAROLD D., Salesman, Electrical Engineers Equipment Co.; res., 6804 Hurlbut Ave., Chicago, Ill.

STILES, LEONARD P., District Sales Manager, Northern Electric Co., Ltd., 131 Simcoe St., Toronto, Ont., Canada.

STINE, W. E., Testing Laboratory, Navy Yard, New York; res., 611 Fairview Ave., Brooklyn, N. Y.

SYRIOS, VASILIOS, Electrical Contractor, 1949 Columbus Ave., Roxbury; res., 426 Tremont St., Boston, Mass.

TARR, HAROLD E., Construction Supervisor, New England Tel. & Tel. Co., 245 State St., Boston, Mass.

TINDALL, VERNE L., Graduate Student in Electrical Engineering, Standford University; res 481 Lytton Ave., Palo Alto, Cal.

TOJO, KIICHI, Engineer, Shibaura Engineering Works, Kanasugi, Shiba, Tokyo, Japan.

VAN ASPEREN, CORNELIS H., Engineering Dept., Hydro-Electric Power Commission of Ontario, 8 Strachan Ave., Toronto, Ont.

VIPOND, JAMES E., Electrical Draftsman, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont.

WAGNER, LEROY R., Asst. Electrical Engineer, Board of Street Railway Commissioners, 314 Murphy Bldg.; res., 386 Glynn Court, Detroit, Mich.

WARNER, ROBERT W., Asst. Engineer, Topeka Edison Co.; res., 1312 Garfield Ave., Topeka, Kansas.

WENK, ROY E., Electrical Draftsman, Puget Sound Power & Light Co.; res., 7764 14th Ave. S. W., Seattle, Wash.

WERTZ, CYRIL J., Instructor of Electrical Engineering, Cornell University; res., 125 Quarry St., Ithaca, N. Y.

WHEELER, STANLEY M., Engineer, Control Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Westinghouse Club, Wilkinsburg, Pa.

WHISTMAN, EDWIN L., Construction Foreman, General Electric Co., 927 Monadnock Bldg., Chicago, Ill.

WHITSON, JAMES H., Chief Electrician, J. C. Widman Co.; res., 115 East Warren Ave., Detroit, Mich.

*WIATT, FRANK E., Chief Draftsman, Union Gas & Electric Co., Front & Rose Sts., Cincinnati, Ohio.

*WIGGS, G. LORNE, Sales Engineer, Canadian Crocker-Wheeler Co., McGill Bldg.; res., 152 Hutchison St., Montreal, Que.

*WILDER, WILLARD S., Asst. General Foreman, Meter & Testing Dept., The Milwaukee Electric Railway & Light Co.; res., 1812 Chambers St., Milwaukee, Wis.

WILLEY, DEAN F., Asst. Engineer, Test Dept., N. Y., N. H. & H. R. R., New Haven, Conn.

WILSON, WILLIAM S., Draughtsman, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

WITT, LEROY C., Maintenance Engineer, Utah Power & Light Co., Grace, Idaho.

*YOUNG, BENJAMIN U., Asst. in Engineering Dept., Western Light & Power Co.; res., 1012 14th St., Boulder, Colo.

YOUNG, HADLEY E., Draftsman, Westinghouse Electric Products Co., Mansfield, Ohio.

YOUNG, HUGH E., Engineer of Bridge Design, City of Chicago; res., 2100 Estes Ave., Chicago, Ill.

*Former enrolled students.

Total 117.

ASSOCIATE RE-ELECTED JANUARY 14, 1921

KENT, JAMES M., Teacher & Consulting Engineer, Manual Training High School, Kansas City, Mo.

ASSOCIATE REINSTATED JANUARY 14, 1921

HUDSON, WALTER F., Chief Electrical Engineer, Utica Gas & Electric Co., 222 Genesee St., Utica, N. Y.

MEMBERS ELECTED JANUARY 14, 1921

ALLEN, ROY N., Vice-President, Supervising Engineer, Colby Steel & Engineering Co., 446 Central Bldg., Seattle, Wash.

CARTER, HERBERT G., Principal Assistant, Chief Electrical Engineer's Branch, Public Works Dept., Sydney, Australia.

COPP, FRANK T., Electrical Engineer, with H. N. Moody, 815 Perdido St., New Orleans, La.

FARMER, KENNETH V., Asst. Supt., Electric Dept., Syracuse Lighting Co., 335 S. Warren St., Syracuse, N. Y.

FULLER, JAMES C., Asst. Telegraph Engineer, Posts & Telegraphs Dept., Federated Malay States, Perak, Federated Malay States.

McQUOWN, WILLIAM K., Captain, United States Army, 1222 Munitions Bldg., Washington, D. C.

MICHELL, FRANK H., Chief Electrician, Langlaagte Consolidated Gold Mining Co., Langlaagte, Johannesburg, S. Africa.

NOBLE, EGERTON S., General Supt., Northern Canada Power Co., Ltd., Timmins, Ont., Canada.

PATCH, JAMES W., Designing Engineer, Transformer Engineering Dept., General Electric Co., Ft. Wayne, Ind.

SHOWALTER, JOSEPH, Consulting & Electrical Tests, Concord, Ont., Canada.

SINDEBAND, MAURICE L., Electrical Engineer, American Gas & Electric Co., 30 Church St., New York, N. Y.

SOUTHERN, GILBERT, Electrical Engineer, Mills, Rhines, Bellman & Nordhoff, 1234 Ohio Bldg., Toledo, Ohio.

TEMPLE, FRED REMINGTON, Outside Plant Engineer, Michigan State Telephone Co., 185 Cass Ave., Detroit, Mich.

WILMOT, LOUIS B., Consulting Engineer, Oceana Buildings, Simmonds St., Johannesburg, Transvaal, S. A.

TRANSFERRED TO GRADE OF FELLOW JANUARY 14, 1921

HAMILTON, JAMES L., Chief Engineer, Century Electric Co., St. Louis, Mo.

HIBBARD, HARRY L., Manager, Marine Dept., Cutler-Hammer Mfg. Co., New York, N. Y.

LILJENROTH, FRANS G., Consulting Engineer, E. I. du Pont de Nemours & Co., Wilmington, Del.

TRANSFERRED TO GRADE OF MEMBER JANUARY 14, 1921

ANDRUS, RAYMOND J., Operating Engineer, Central Power Co., Grand Island, Neb.

BOLSER, M. O., Technical Asst., Distribution Dept., Bureau of Power & Light, Los Angeles, Cal.

DOWNTON, PERCIVAL G., Branch Manager, Electric Storage Battery Co., Minneapolis, Minn.

DRAKE, CHESTER W., General Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

FIRESTONE, SIEGMUND, Consulting Engineer, Rochester, N. Y.

GENT, RUFUS T., Plant Engineer, Hydro-Electric Power Commission, Niagara Falls, Ont.

LOCKYER, R. H. N., Engineer in Charge, West Kootenay Power & Light Co., Trail, B. C.

MILLAN, WALTER H., Supt. of Substations, Union Electric Light & Power Co., St. Louis, Mo.

NELSON, NORMAN C., Electrical Engineer, North Pacific Public Service Co., Bremerton, Wash.

NOTOMI, IWAICHI, Director, Shibaura Engineering Works, Tokyo, Japan.

POTTER, CHARLES P., Engineer in Charge, Large Motor and Transformer Engineering Depts., Wagner Electric Mfg. Co., St. Louis, Mo.

ROBERTSON, ARTHUR S., Erection Engineer, Hydro-Electric Power Commission, Niagara Falls, Ont.

ROSWELL, CHARLES M., Engineer, Charleston Consolidated Railway & Light Co., Charleston, S. C.

SIMONSON, GEORGE M., Chief Electrical Engineer, State of California Department of Engineering, Sacramento, Cal.

TAYLOR, EDWARD, Designing Engineer, General Electric Co., Chicago, Ill.

VOLKMANN, WILLIAM, JR., Assistant to Chief Engineer, Toronto Power Co., Toronto & Niagara Power Co., Toronto Railway Co., Toronto, Ont.

WARNER, WILLIAM H., Distribution Engineer, New York & Queens Electric Light & Power Co., Long Island City, N. Y.

YAMBERT, D. W., Electrical Engineer, France Stone Co., Toledo, O.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held January 3, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

RIDDILE, J. S., Manager of Power, Laurentide Power Co. Ltd., Grand Mere, Quebec.

To Grade of Member

ANDERSON, OSCAR V., Superintendent, Distribution Dept., Toronto & Niagara Power Co. and Toronto Railway Co., Toronto, Ontario.

BAKER, CAREY W., Engineer, Transformer Dept., Canadian Westinghouse Co., Hamilton Ont.

BEAUBIEN, JAMES DE GASPE, Consulting Engineer, Montreal, Quebec.

COLE, HORACE L., Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

CORIELL, LOUIS D., Periodontist and Radiologist, Baltimore, Md.

HAISLIP, RICHARD A., Telephone Engineer, Dept. of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

HEWSON, WILLIAM G., Railway Engineer, Hydro-Electric Power Commission, Toronto, Ont.

HOLMES, HOWARD A., Engineer, Morris Knowles, Inc., Pittsburgh, Pa.

KENT, JAMES MARTIN, Teacher and Consulting Engineer, Manual Training High School, Kansas City, Mo.

SEABURY, RICHARD W., President, Boonton Rubber Mfg. Co., Boonton, N. J.

WALTER, HENRY C., Electrical Engineer, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1921.

Albright, John A., Jr., Syracuse, N. Y.
Allen, Asa E., Dallas, Texas
Alson, C. Robert, Milwaukee, Wis.
Andrews, Ralph J., Jackson, Mich.
Aschenbreuer, Rudolph, Milwaukee, Wis.
Ashenden, Harry B., Milwaukee, Wis.
Aspinwall, George L., Boston, Mass.
Bailey, George L., New York, N. Y.
Baker, Charles F., Charleroi, Pa.
Baldwin, Benjamin W., St. Paul, Minn.
Ballantyne, William M. H., Holtwood, Pa.
Bany, Herman, Schenectady, N. Y.
Barnes, Charles T., Toronto, Ont.
Bastian, Harry S., Portland, Ore.
Bearse, Edwin W., Atlanta, Ga.
Beavers, Franklin J., Gary, Ind.
Bell, Fred N., E. Pittsburgh, Pa.
Benn, Sylvester M., Schenectady, N. Y.
Beyers, Harry, New York, N. Y.
Birckhead, Lennox, (Member), Baltimore, Md.
Bird, Clarence A., (Member), Chicago, Ill.
Biswanger, Charles W., Newark, N. J.
Bloomberg, Sheldon, E. Pittsburgh, Pa.
Bodge, Harold H., (Member), Boston, Mass.
Bolster, Frank T., Syracuse, N. Y.
Bostwick, Henry M., Hamilton, Ont.
Boyer, Floyd H., Des Moines, Iowa
Boyle, John J., Niagara Falls, N. Y.
Bradley, Edward F., Milwaukee, Wis.
Brien, Fred P., McAllen, Texas
Brown, J. T., New York, N. Y.
Brunner, Earle M., Portland, Ore.
Bull, Willard E., Chicago, Ill.
Burrill, H. G., (Member), Baltimore, Md.
Call, Lloyd L., Detroit, Mich.
Canada, Charles E., Portland, Ore.
Carlisle, George L., Pittsburgh, Pa.
Carter, Charles S., Ampere, N. J.
Caverly, Arthur S., Fitchburg, Mass.
Chapman, Oliver D., Springdale, Pa.
Cheney, William L., Woonsocket, R. I.
Cherry, Talmadge C., (Member), Syracuse, N. Y.
Choate, Davie C., Grand Forks, N. Dakota
Clarke, Henry A., Baltimore, Md.
Cohoon, G. D., Toronto, Ont.
Cole, Charles H., San Francisco, Cal.
Coleman, Homer H., Petersburg, Fla.
Coles, David J., Philadelphia, Pa.
Collard, Alleson R., New York, N. Y.
Corl, Marshall P., E. Pittsburgh, Pa.
Condon, Thomas R., Chicago, Ill.
Coshway, Eugene J., Jr., Syracuse, N. Y.
Cook, Edward T., Sacramento, Cal.
Coolidge, William A., Boston, Mass.
Critzas, Demosthenes J., New York, N. Y.
Cronk, Harold W., Toronto, Ont.
Crowdus, James A., St. Louis, Mo.
Crymble, Alfred C., Jacksonville, Fla.
Cummins, Thomas R., Schenectady, N. Y.
Cundall, Harold C., New York, N. Y.
Cutler, Clarence W., Schenectady, N. Y.
Dale, Oswald, Irvington, N. J.
Darlington, Paul W., Milwaukee, Wis.
Davey, Charles B., Chicago, Ill.
Davidson, Roy J., Portland, Ore.
Davies, John R., Los Angeles, Cal.
Davis, Daryl D., Vacaville, Cal.
Davis, William S., (Member), Newark, N. J.
Dennis, Samuel W., Pittsburgh, Pa.
Diaz, Pedro, Los Angeles, Cal.
Dillard, Earle M., Springfield, Ohio
Donahue, John H., New York, N. Y.
Doron, Joseph W., Jr., Hamilton, Ohio
Dorsey, Edward P., Hartford, Conn.
Doughty, Horace J., Toronto, Ont.
Douglass, Earl C., E. Pittsburgh, Pa.
Dows, Chester L., (Member), Cleveland, Ohio
Dwyer, Frank T., Syracuse, N. Y.
Dyer, Fred, St. Louis, Mo.
Eastom, Frank A., Boulder, Colo.
Eaton, Samuel E., New York, N. Y.
Edinger, Frederick, P., Syracuse, N. Y.
Edmunds, A., Milwaukee, Wis.
Edwards, Carl D., Charleroi, Pa.
Eggen, Charles B., Scott City, Kansas
Elder, George R., Lynchburg, Va.
Elliott, Roy K., (Member), Boston, Mass.
Ellwanger, Edward C., Schenectady, N. Y.
Elz, George A., Roxbury, Mass.
Esterling, Ollie S., Ashland, Ore.
Esty, Edward S., Pawtucket, R. I.
Ettinger, Victor P., St. Louis, Mo.
Evans, G. L., (Member), St. Louis, Mo.
Everly, Harold A., (Member), Holtwood, Pa.
Farbanish, Frank, Milwaukee, Wis.
Feldtkeller, Carl L., Milwaukee, Wis.
Fernholz, William H., (Member), Milwaukee, Wis.
Ferris, Richard B., Long Island City, N. Y.
Fish, Joseph P., (Member), Boston, Mass.
Flemister, Simon A., Atlanta, Ga.
Freeman, Ernest B., Hyde Park, Mass.
Fregin, Norman H., Syracuse, N. Y.
Fukuda, Minoru, New York, N. Y.
Gage, David H., New York, N. Y.
Gardner, Earl W., Portland, Ore.
Gease, Walter C., Milwaukee, Wis.
George, Rolland E., E. Pittsburgh, Pa.

Gilliland, Clarence R., Cincinnati, Ohio
Godard, William W., Atlanta, Ga.
Gordon, Robert E., Clarksburg, W. Va.
Gould, Harry A., (Member), Schenectady, N. Y.
Gould, LeRoy B., Manchester, N. H.
Grainger, William W., St. Louis, Mo.
Grant, John, Chadwicks, N. Y.
Grasser, Arthur P., Cleveland, Ohio
Graves, Robert C., Plainville, Conn.
Griffin, C. Brewer, (Member), Springfield, Mass.
Grover, Frederick, Schenectady, N. Y.
Guest, Thomas E., St. Catharines, Ont.
Guse, Clarence E., Schenectady, N. Y.
Gustafson, Allen L., Des Moines, Iowa
Hall, Voris B., Lewisburg, Pa.
Hanover, Edward A., Rochester, N. Y.
Hanscom, Robert M., W. Lynn, Mass.
Harkins, John M., Toronto, Ont.
Henderson, Joel L., Roanoke, Va.
Henroid, Maurice A., Mansfield, Ohio
Henry, Donald A., (Member), Springfield, Ill.
Henton, Stuart C., (Member), Akron, Ohio
Hess, Joseph C., Philadelphia, Pa.
Hiss, Charles A., Philadelphia, Pa.
Hjort, Alf, (Member), New York, N. Y.
Hobbins, W. D., Milwaukee, Wis.
Hoeft, Edwin W., Milwaukee, Wis.
Holbrook, Augustus T., (Member), New York, N. Y.
Hollenbeck, Charles S., New York, N. Y.
Howard, John J., New Haven, Conn.
Howard, William U., New York, N. Y.
Huniston, H. A., Cleveland, Ohio
Hunt, Gates E., Milwaukee, Wis.
Hunt, Lloyd F., E. Pittsburgh, Pa.
Hussey, John A., Essington, Pa.
Ilyus, Edmund B., Bethlehem, Pa.
Inaba, Shigeharu, Schenectady, N. Y.
Ingram, Clyde O., Akron, Ohio
Jardine, Ernest I. W., Toronto, Ont.
Jenks, Harold C., E. Pittsburgh, Pa.
Jinks, Sam, Hammond, Ind.
Johnson, Clement B., New York, N. Y.
Johnson, James F., Midland, Mich.
Johnston, George A., Boulder Colo.
Jones, D. Clyde, Rochester, N. Y.
Jones, David M., Schenectady, N. Y.
Kattens, John P., Aguilar, Colo.
Kerswell, Frank, Emplame, Sonora Mexico.
Kinney, Harmon C., Philadelphia, Pa.
Kirkpatrick, F. O., (Member), Cincinnati, Ohio
Klinck, Charles C., Jr., Buffalo, N. Y.
Kling, Ralph B., Chicago, Ill.
Knight, Edward D., Kayford, W. Va.
Kobak, Edgar, St. Louis, Mo.
Krapf, Herman C., Pittsburgh, Pa.
Kriegl, Otto, W. Allis, Wis.
Kroeger, Michael, J., Minneapolis, Minn.
LaFontaine, Leo P., Spirit Lake, Iowa
Laing, William L., Montour Falls, N. Y.
Larulle, E. A. D., Milwaukee, Wis.
Latch, Harvey S., Fort Collins, Colo.
Launder, Arthur I., Seattle, Wash.
Law, John B., Jr., Atlanta, Ga.
Layton, William M., Mansfield, Ohio
Lechner, George J., Cleveland, Ohio
LeClair, Titus G., Moscow, Idaho
Leet, Charles M., Indianapolis, Ind.
Leonard, Charles E., Champaign, Ill.
Letts, Everett DeW., Cleveland, Ohio
Locke, Francis J., New York, N. Y.
Lockett, Ralph G., Milwaukee, Wis.
Lockwood, E. Stanley, Jersey City, N. J.
Long, V. M., Miami, Ariz.
Loveland, Washington W., Syracuse, N. Y.
MacDonald, Cecil, J., Scranton, Pa.
MacFadden, Harry A., New York, N. Y.
Malady, John A., Pittsburgh, Pa.
Manookin, Kerrigan M., Evanston, Wyoming
Mantri, Pandurang A., W. Lynn, Mass.
Marden, Ralph C., Manchester, N. H.
Marrotte, Louis H., Montreal, Que.
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Maxson, Rolland H., Milton, Wis.
Meece, James C., Portland, Ore.
Mekelburg, Earl F., Milwaukee, Wis.
Messinger, Lucien E., Chicago, Ill.
Meyers, George, Manning, Iowa
Miles, George E., Winnipeg, Man.
Miller, Edwin C., New York, N. Y.
Miller, Peter C., Buckley, W. Va.
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Miyasaki, Komakichi, New York, N. Y.
Molinet, Enrique R., Ithaca, N. Y.
Montgomery, Howell C., Bradford, Pa.
Moore, Leon H., Schenectady, N.Y.
Morgans, Frank D., El Centro, Cal.
Mowbray, Frank E. H., Hamilton, Ont.
Munkelertz, Norman R., Schenectady, N. Y.
Murray, James S., Chicago, Ill.
Murray, John S., Toronto, Ont.
Mustard, John H., (Member), Chapel Hill, N. C.
McAulippe, John C., Jr., New York, N. Y.
McBerty, Ford H., Buffalo, N. Y.
McCormick, James R., Jr., Lynn, Mass.
McCreary, Oliver L., Chicago, Ill.
McCulloch, William W., Jr., Marietta, Ga.
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McGuire, Milton H., McMinniville, Ore.
McLaughlin, Edward J., Waterville, Me.
McNeely, John K., (Member), Urbana, Ill.
Nettleton, Leroy A., E. Pittsburgh, Pa.
Newmeyer, William L., E. Pittsburgh, Pa.
Newton, Earl F., Concord, N. H.
Newton, Jay E., Madison, Wis.
Nielson, Johannes M., New York, N. Y.
Norman, Horace M., E. Pittsburgh, Pa.
Nostrand, John W., New York, N. Y.
Nottage, Stanley G., E. Pittsburgh, Pa.
Oates, Malcolm, N., Baltimore, Md.
Oesterbrock, William C., Cincinnati, Ohio
Oesterreich, Edmund W., Chicago, Ill.
Oneal, Lloyd E., New York, N. Y.
Orr, Lester B., Chicago, Ill.
Ostergren, Clarence N., Atlanta, Ga.
Owen, Roy J., Syracuse, N. Y.
Paxton, Carroll W., Revesville, W. Va.
Peacey, Norman C., Camden, N. J.
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Pollock, Robert T., Boston, Mass.
Porta, Peter, Brooklyn, N. Y.
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Prevost, Maurice, Montreal P. Q.
Purcell, James N., New York, N. Y.
Pyle, Mack L., Bridgeport, Ala.
Quigley, Don L., Champaign, Ill.
Quinlan, Walter J., New York, N. Y.
Quinn, Edward, New York, N. Y.
Radcliffe, Karl W., Milwaukee, Wis.
Randall, Harry B., Pittsburgh, Pa.
Rapp, Ralph L., Schenectady, N. Y.
Rath, Edwin R., Pittsburgh, Pa.
Read, George J., Pittsburgh, Pa.
Reed, Harold D., Boston, Mass.
Reemelin, Oscar B., Dayton, Ohio
Reese, Hal. F., Portland, Ore.
Rice, Harold F., Schenectady, N. Y.
Rice, Stanley I., New York, N. Y.
Richardson, Max C., N. Canton, Ohio
Ritter, Jacob H., Derry, Pa.
Rivero, Arsene, E. Pittsburgh, Pa.
Roberts, Eugene A., Carlsbad, New Mexico
Robinson, Samuel, Schenectady, N. Y.
Robue, Burton A., Whitinsville, Mass.
Rolle, Sylvan D., Philadelphia, Pa.
Roloff, Robert W., St. Marys, Pa.
Rothstein, Michael, Long Island City, N. Y.
Round, Howard Y., Cleveland, Ohio
Rueppel, Edwin G., New York, N. Y.
Rumbough, William S., Urbana, Ill.
Rust, Louis J., Springfield, Ill.
Rustad, Aksel T., Milwaukee, Wis
Rutherford, Thomas B., New York, N. Y.
Rutz, E. C., Chicago, Ill.
Ryan, William E., Springdale, Pa.
Ryder, Horace A., Chicago, Ill.
Rymer, Donald H., Helena, Mont.
Safford, Charles I., Salem, Ore.
Sanders, Marion S., Roanoke, Va.
Sargent, Claude O., Philadelphia, Pa.
Sarson, Millard, R., Long Beach, Cal.
Saunders, J. Leo, Cape Madeline, Que.
Sawyer, Lynn, Roosevelt, Ariz.
Schofield, Albert, Toronto, Ont.
Schuder, Robert C., Chicago, Ill.
Scott, Lee R., Watertown, N. Y.
Shmied, Ernest A., Sioux City, Iowa
Sicard, J. N., Three Rivers, P. Q.
Smith, Delbert E., Manchester, N. H.
Smith, Robert H., Beeville, Texas
Spaenkuch, Ernest C., New Haven, Conn.
Speer, Guy F., Milwaukee, Wis.
Spicer, Earl E., Catalina Island, Cal.
Spring, John H., St. Catharines, Ont.
Stackhouse, Clifton C., Washington, D. C.
Stanton, George T., Columbus, Ohio
Stayner, J. Hyde, Salt Lake City, Utah
Sterba, Ernest J., New York, N. Y.
Stevens, Don L., New York, N. Y.
Stevens, Walter F., Boston, Mass.
Storz, Jacob F., Ethel, La.
Tada, Torso, New York, N. Y.
Talbot, Thomas F., Schenectady, N. Y.
Talbott, Arnold M., New York, N. Y.
Tarboux, Joseph G., Utica, N. Y.
Tavenner, Frank L., Deer Lodge, Mont.
Taylor, Edward W., Newark, N. J.
Tesch, Walter C., Milwaukee, Wis.
Thompson, John H., Ottawa, Ont.
Throop, Albert R., Chicago, Ill.
Thurber, James P., Boston, Mass.
Tinker, Edward L., West Haven, Conn.
Tittle, Harry W., Akron, Ohio.
Titus, Conrad, Richford, Vt.
Toeppen, Manfred K., Detroit, Mich.
Tracy, J. Lee, New York, N. Y.
Trull, Frederick G., Toronto, Ont.
Trivett, Martin A., New York, N. Y.
Turner, R. B., E. Pittsburgh, Pa.
Turner, Theo. J., Jamestown, N. Y.
Turner, William M., Philadelphia, Pa.
Vernon, Ford H., San Francisco, Cal.
Wagner, Henry O., Detroit, Mich.
Waintraub, Alexander, New York, N. Y.
Wainwright, Stuart F., Los Angeles, Cal.
Walton, Albert, (Fellow), Eau Claire, Wis.
Walz, James O., E. Pittsburgh, Pa.
Wardle, Bertram, St. Catharines, Ont.
Ware, John S., (Member), Newark, N. J.
Waters, W., Toronto, Ont.
Weber, John J., Hammond, Ind.
Weir, William, Puebla, Mexico.
Westin, Carl L., E. Pittsburgh, Pa.
Whitbeck, Howard S., Kennewick, Wash.
Wigglesworth, Frank, Boston, Mass.
Wildes, Karl L., Cambridge, Mass.
Wilkinson, Thomas W., Kansas City, Mo.
Willen, Nils G., New York, N. Y.
Williams, Alexander T., Ampere, N. J.
Williams, H. H., E. Pittsburgh, Pa.
Williams, James P., Portland, Ore.
Wittlinger, Carl A., (Member), Tompkinsville, S. I., N. Y.
Wood, Joyce L., Portland, Ore.
Wortman, Joseph C., St. Marys, Pa.
Wyckoff, John S., Jr., E. Pittsburgh, Pa.
Whyte, James S., Shawinigan Falls, P. Q.
Young, Louis, T., (Member), Los Angeles, Cal.
Zubick, John W., (Member), New York, N. Y.
Total 350.

Foreign

Abraham, Frederick H., Bradford, Yorkshire, Eng.
Blunt, William J., Christchurch, N. Z.
Bodenschatz, Heinrich, Altona-Behrendeld, Germany.
Fukunaka, Sataro, (Member), Imabashi, Osaka, Japan.
Jack, Hugh, Rugby, Eng.
Lee, T. J. B., Baraque, Cuba.
Mazda, Chisaburo, Kyoto, Japan.
Murray, Burnett M., Shanghai, China.
Tatsumi, Tamitaro, Omuta-shi, Fukuokaken, Japan.
Washington, George L., Havana, Cuba.
Weicker, William, Hermsdorf, Germany.
Wicks, E. B. E., Christchurch, N. Z.
Wilson, William H., Colombo, Ceylon.
Wright, M. M., Christchurch, N. Z.
Yoshio, Tsuzuki, Omuta, Fukuokaken, Japan.
Total 15.

STUDENTS ENROLLED JANUARY 14, 1921

12503 Buchanan, James P., Jr., University of Texas
12504 Lain, Claud B., University of Texas
12505 Bryan, Ottis L., University of Texas
12506 Antony, Lawrence J., Tri-State College of Engineering
12507 Dickinson, Jackson M., Alabama Polytechnic Institute
12508 Densmore, Richard D., Cornell University
12509 Shaver, Bernard K., Cornell University
12510 Walton, Richardson L., Cornell University
12511 Shaw, Alfred E., Iowa State College
12512 Butterfield, George L., Notre Dame University
12513 Tuftee, Lewis G., Tri-State College of Engineering
12514 O'Donnell, Edward L., Pratt Institute
12515 Bisbee, Burton A., University of Minnesota
12516 McVean, Norman S., University of Minnesota
12517 Heidelberger, Roy J., University of Minnesota
12518 Engen, Ralph E., University of Minnesota
12519 Johnson, Robert A., University of Minnesota
12520 Brince, Frank J., University of Minnesota
12521 Eubank, Charles G., University of Minnesota
12522 McEachin, John L., University of Minnesota
12523 Fiske, Harold C., University of Minnesota
12524 Wichman, M. F., University of Minnesota
12525 Bergstrom, Marlow B., University of Minnesota
12526 Willard, A. C., University of Minnesota
12527 Nielson, Walter McK., University of Minnesota
12528 Sorensen, John E., University of Minnesota
12529 Jacoby, Samuel F., Drexel Institute
12530 Port. Raymond F., Syracuse University
12531 Studley Gerard L., Wentworth Institute
12532 Danneler, Michael A., Marquette University
12533 Pierick, E. T., Marquette University
12534 Reed, Philip D., University of Wisconsin
12535 Friedrich, Herbert L., University of Texas
12536 Ruggles, Edward W., North Carolina State College of A. & M.
12537 Finn, David J., A. & M. College of Texas
12538 Clarke, Carole A., Mass. Institute of Technology
12539 Tooher, James L., University of Colorado
12540 Lee, Joses B., University of California
12541 Kelly, Francis C. O., University of Colorado
12542 Doud, Arthur M., University of Colorado
12543 Rust, Edgar H., University of Colorado
12544 Johnson, Einar D., Worcester Polytechnic Institute
12545 Berry, Donald L., New York Electrical School
12546 Rearden, James R., Clemson Agr. College
12547 Clatworthy, Walter M., Clemson Agr. College
12548 Stevenson, Carl A., Clemson Agr. College
12549 Somers, Frederick W., Tri-State of Engineering
12550 Toth, Joseph, Jr., Tri-State College of Engineering
12551 Braden, Rene A., University of Minnesota
12552 Bothun Elmer O., University of Minnesota
12553 Klatt, Reinhold K., University of Iowa
12554 Reilly, William C., University of Iowa
12555 Anderson, Raynor G., University of Iowa
12556 Schacht, Ray L., University of Iowa
12557 Bank, Martin L., University of Iowa
12558 Mathews, Roy E., University of Iowa
12559 Schump, Arthur L., University of Iowa
12560 Tompkins, Raginald J., University of Iowa
12561 Curtis, Harry B., University of Arkansas
12562 Britt, James E., University of Arkansas
12563 Shilts, Walter L., University of Notre Dame
12564 Perry, Oliver A., School of Engineering of Milwaukee
12565 Wosnitzer, John, Stevens Institute of Technology
12566 Lang, Thomas R., Toronto Central Technical School
12567 Varbedian, Vahan G., University of Iowa
12568 Underwood, Henry M., Pratt Institute
12569 Drake, Stanley E., Pratt Institute
12570 Kinney, Adrien H., Wentworth Institute
12571 Murphy, George F., Pratt Institute
12572 Hall, Charles F., Colorado Agricultural College
12573 Baldwin, John F., Drexel Institute
12574 Farmer, Ernest E., Toronto Central Technical School
12575 Hannah, Edward R., Toronto Central Technical School
12576 Balfour, Charles H., Jr., Virginia Military Institute
12577 Ashley, James R., Virginia Military Institute
12578 Blackwell, Paul A., Virginia Military Institute
12579 Cobb, Beverly C., Virginia Military Institute
12580 Crist, James F., Virginia Military Institute
12581 Harwood, Edward E., Jr., Virginia Military Institute
12582 Jones, Hoyt, Virginia Military Institute
12583 Land, Henry C., Virginia Military Institute
12584 Lockey, William H., Virginia Military Institute
12585 McCulloch, Roderick R., Virginia Military Institute
12586 Mars, Clarke B., Virginia Military Institute
12587 Paxton, Powell L., Virginia Military Institute
12588 Syme, Samuel A., Virginia Military Institute
12589 Vaughan, Fort F., Virginia Military Institute
12590 Weaver, Richard C., Virginia Military Institute
12591 Wessells, Stewart A., Virginia Military Institute
12592 Wilmer, Frederic P., Virginia Military Institute
12593 Womeldort, Leslie, Virginia Military Institute
12594 Smith, John L., Virginia Military Institute
12595 Butler, George M., Colorado Agricultural College
12596 Knapp, Forrest L., Colorado Agricultural College
12597 Moore, Clarence A., Colorado Agricultural College
12598 Zachrisen George W., Colorado Agricultural College
12599 Munson, Lawrence A., Colorado Agricultural College
12600 Abrams, Myron L., Colorado Agricultural College
12601 Garrett, Perry B., Colorado Agricultural College
12602 Burley, Paul B., University of Illinois
12603 Watson, Howard J., University of Michigan
12604 Boxer, Julius, Cooper Union
12605 Stinson, James B., Pratt Institute
12606 Mumma, Levi B., Purdue University
12607 Wahl, Richard P., Purdue University
12608 Warren, Edward R., Purdue University
12609 Ruese, Wilbur H., Purdue University
12610 Specht, Max H., Purdue University
12611 Lum, Sun. Purdue University
12612 Pearcy, Noah C., Purdue University
12613 Robbins, Floyd D., University of Washington
12614 Packard, Dexter R., University of Washington
12615 Baker, Albert L., University of Washington
12616 Selton, Nuben, University of Washington
12617 Cochran, Lyall B., University of Washington
12618 Cowley, Francis C., University of Washington

12619 Conroy, Edward W., University of Washington
12620 Drake, Edward F., University of Washington
12621 Bird, Lester F., University of Washington
12622 Hanger, Cecil T., New York Electrical School
12623 Burckmeyer, Lawrence A., Jr., Clemson Agricultural College
12624 Drew, Leslie A., University of Illinois
12625 Fitch, Clifford S., Michigan Agricultural College
12626 Fleming, Harold L., Michigan Agricultural College
12627 Erickson, Claud R., Michigan Agricultural College
12628 Brown, Carl M., Michigan Agricultural College
12629 Floten, Donald W., Michigan Agricultural College
12630 Kalm, Arnold V., Michigan Agricultural College
12631 Cummings, Glenn R., Michigan Agricultural College
12632 Keller, Paul H., University of Michigan
12633 Snell, DeWitt S., Union College
12634 Landergott, Anton F., School of Engineering of Milwaukee
12635 Bush, Willis H., California Institute of Technology
12636 Dagg, Hueston W., California Institute of Technology
12637 Hickey, Artemas S., Jr., California Institute of Technology
12638 Keith, Clyde R., California Institute of Technology
12639 Langlie, Paul J., California Institute of Technology
12640 Macurda, Malcolm, California Institute of Technology
12641 Quirmbach, Charles F., California Institute of Technology
12642 Seares, Richard U., California Institute of Technology
12643 Smith, George K., California Institute of Technology
12644 Stratford, John P., California Institute of Technology
12645 Wilson, Will F., California Institute of Technology
12646 Hildebrandt, John L., Johns Hopkins University
12647 Weible, Carl J., Pratt Institute
12648 Mahnke, E. Cris., Tri-State College of Engineering
12649 Clegg, Arthur E., Westinghouse Technical Night School
12650 Gustafson, Clifford W., Michigan Agricultural College
12651 Lanmark, Oal J., University of Minnesota
12652 Redmon, Roy S., University of Cincinnati
12653 Wu, Hsin-Ping, Cornell University
12654 Hall, Harvey W., Northeaston College
12655 Thomason, Frederick L., Pratt Institute
12656 Rothholz, John Hopkins University
12657 Bechler, William C., Jr., Drexel Institute
12658 Robles, G., School of Engineering of Milwaukee
12659 Hooks, George M., Pennsylvania State College
12660 Carlson, Frank E., University of Detroit
12661 Talley, B. B., Oklahoma A. & M. College
12662 Taylor, Wilfred A., University of Maine
12663 Behan James W., New York Electrical School
12664 Musser, Robert L., Pennsylvania State College
12665 Dow, Arthur G., University of Maine
12666 Larsen Ernest L., University of Minnesota
12667 Van Hook, Raymond, A. & M. College of Texas
12668 Leinbach, Charles C. B., Pennsylvania State College
12669 Herr, Clarence K., University of Idaho
12670 Thomas, Douglas V., A. & M., College of Texas
12671 Waters, Frank N., Oregon Agricultural College

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A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives will be found in the January issue of the JOURNAL and will be published again in the June issue.)

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A complete list of the 39 Sections and 61 Branches of the Institute, with the names of the chairmen and secretaries, will be found in the January issue of the JOURNAL and will be published again in the June issue.

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The Effect of Heat on Paper Insulation

BY H. W. FISHER and R. W. ATKINSON

Both of Standard Underground Cable Company.

A discussion is given in detail of the mechanical properties of paper especially as influenced by drying, heating, and impregnating. Tests for measuring the changes due to these causes are discussed and it is shown that tensile tests are unsatisfactory for this purpose. A measurement of tearing resistance is found to be satisfactory and two machines for this purpose are described. Measurements are given of rate of deterioration of paper at different temperatures. The relation of these data to allowable operating temperature is considered.

No discussion is given of the various causes including heating due to dielectric losses which affect the limiting temperature of high-voltage cables.

The rapid increase of deterioration with temperature is shown. Emphasis is placed on the importance of not exceeding intended temperatures through lack of knowledge of conditions.

IN a discussion of the limiting temperature for paper insulation of low-voltage cables, the matter for first consideration is the effect of high temperature upon the properties of the material. The principal importance of this effect lies in the reduction of the mechanical strength of the paper. In the case of low-voltage cable, the only changes in electrical properties of importance are incidental to the mechanical changes and therefore a discussion of these mechanical changes forms a complete basis for consideration of temperature limitation.

The deterioration of paper due to continued high temperature is not measured by change of tensile strength of the paper. The change is apparent in reduced ability to withstand tearing forces, or bending or folding. Satisfactory study of aging of paper can be made only with the use of suitable apparatus for measuring one or more of these properties. This article includes description of instruments for this purpose as well as data of a considerable number of tests made on paper, after various kinds of heat treatment, as described.

Following the report of experimental data is a discussion of the question of temperature rating of this class of insulating material. The effect of high temperature upon the impregnating medium is not considered in detail except in-so-far as the rate of deterioration of the paper may be influenced by the medium.

If a quantity of paper of uniform quality is subjected to a high temperature and successive samples are taken from it, from time to time, it will be found that the successive samples differ progressively in ability to withstand tearing between the fingers, or to withstand without breaking, creasing or bending. The first effect noticeable is the greater ease with which the paper is torn. Later samples may not be creased without cracking. With a further degree of deterioration, it is actually not possible to bend the paper an appreciable amount without breaking. A still further amount of aging produces a material which crumbles to a powder. If the successive samples of paper are subjected to a tensile test made very carefully so as to avoid injury of the nature of incipient tears, or unequal tension on the specimen, it will be found that even those samples which show an evidently reduced ability to withstand tearing, will have as high a tensile strength as originally. In a number of samples which have been subjected to high temperature for sufficient time to produce a very marked decrease in tearing resistance, it will be found that, even though the tensile tests are made very carefully, there will be a wide variation in the strength measured for the individual samples. The maximum readings may be practically as high as the original strength of the paper, though tests on other individual samples fall as low as 40 or 50 per cent of the original value. The fairly apparent cause of this condition is the great difficulty of obtaining an actually fair tensile test on the very brittle material so that only an occasional specimen will show the real tensile strength of actually something near the original value. Of course, as deterioration is increased still farther there is an actual reduction in tensile strength as well as in loss of tearing resistance.

We may now consider the essentials of a suitable method of measuring aging. The requirements are not peculiar to this particular measurement, but they are very frequently overlooked and it is well to make a specific mention of them so as to make a clearer examination of testing methods with these requirements in mind.

Presented at the 9th Midwinter Convention of the A. I. E. E. New York, Feb. 16-18, 1920.

The first requirement is that the property measured is actually a measure or at least an indication of the usefulness of the material to meet the required service conditions.

The second essential of the method of test is that it shall permit definite distinction between samples which are different only in a slight degree. That is, the difference in the measurements of two such samples must be large in comparison with the variations in the measurements on samples which are identical. This constitutes effective sensitivity.

The third requirement is that the measurements be such as to be capable of permanent record and preferably of a definite quantitative form. It is in this particular that the tearing test by hand is unsatisfactory though it meets the first requirement and, to a fair extent, meets the second one.

We believe it is fairly generally recognized that a tearing test by hand meets the first requirement, that is, it measures or indicates the usefulness of paper to meet the service conditions of cable practise. It is well-known in the art that paper containing only the amount of moisture normally present when exposed to the dry air prevalent indoors in winter time, is much more difficult to run in cable wrapping machines than is paper exposed to the high humidity prevalent in summer weather. Also, it is recognized that if paper insulation is damaged by overheating after application to a cable, it is less able to withstand handling and bending such as is incident to installation.

Therefore, a method which shows progressive difference with moisture content and with aging at high temperature, meets, at least as far as concerns these variables, the first requirement of a suitable paper testing device. In any event it fulfills this requirement as far as concerns measurement of aging. It follows from what has been said that a measurement of tensile strength by the ordinary method is quite unsuitable from the standpoint of this first requirement.

From the standpoint of the second requirement, tests of tearing resistance even by hand are fairly satisfactory. Until very recent years, there has been no machine as suitable from this standpoint as the hand test. We will later describe two machines which are very satisfactory from this standpoint. The tensile test is unsatisfactory also from the standpoint of the second requirement.

The difficulty in the way of securing consistent results with a tensile test, on account of accidental damage, etc., suggested the use of a method of testing by damaging the specimen in a certain definite way and then making a tensile test. Such a method of test was standardized by making a transverse cut in the paper for a distance equal to one-quarter of the width of the paper. Tensile tests were then made upon the modified samples. Somewhat more satisfactory results were obtained by noting the elongation of the specimen before rupture, than by noting the tensile strength obtained. This method was in use for some time but was never more than partly successful and has now been abandoned for methods described later.

A machine for testing the tearing resistance of airplane fabric was given in a discussion by F. J. Hoxie at the annual meeting of the American Society of Mechanical Engineers in December 1919. We quote his very brief description: "Tear tests were made on a horizontal testing machine by cutting the specimen three in. wide and placing them in three in. jaws with one in. of cloth between the jaws at the front of the machine and three in. between them at the back." We have seen this method applied on cloth with very satisfactory results. As the test was further developed a transverse cut was made in the cloth on the stretched side before applying the tension test.

A similar problem to that of paper is encountered in the insulated cable industry in the case of varnished

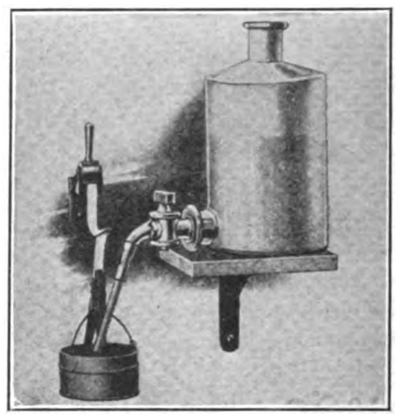

Fig. 1

cambric. It was found that frequently a high tensile strength was found on samples which were obviously inferior from the standpoint of use and also from the standpoint of tearing resistance as measured by hand.

In the attempt to find a suitable machine for testing this material, a type of machine much used in paper testing, a so-called "pop tester," was tried. We were much surprised however to find that the results with this type of machine were quite in accord with the tensile tests and thus did not rank the material in the same order at all as its practical usefulness or as the ranking by tearing resistance as made by hand. The machine used for these bursting tests was one using liquid pressure against a rubber diaphragm which in turn pressed against a strip of the cloth under test. Tests of less extent made on paper showed similar results as far as they were carried. There is a published record of a similar experience of another experimenter with the use of this machine for testing paper. (H. N. Case in the *Journal of Industrial and Engineering Chemistry*, page 49, January 1, 1919.) It is interesting that this writer found the "bursting

test" machine, or "pop tester," a useful addition to his testing equipment, but found that sometimes a desirable test condition is the combination of a high tearing resistance with a *low* test with the "pop tester."

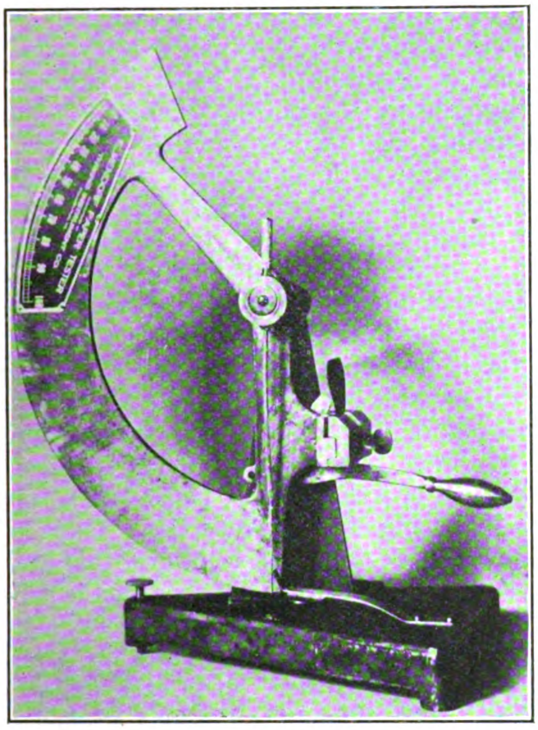

Fig. 2

In the same article is described a "home-made" machine for measuring tearing resistance. Details of test results as used for determining usefulness of paper for various applications, are given. Fig. 1 shows the apparatus described and used by Case. A method developed by the writers and described below was suggested by the successful results obtained by Case with his machine. Case's machine is also of interest in its close resemblance to the apparatus used by Mr. W. A. Del Mar, which I believe will be described in his paper presented at this symposium.

Description is given in an appendix, of the tearing testing machine developed by the writers and on which was obtained much of the data reported herein. This machine differs in the most important degree from the machines of Case and of Del Mar in that the measure of the tearing resistance is made by the use of a spring as a dynamometer instead of by means of a weight in a pan. We refer to this instrument as machine No. 1.

Just before the actual preparation of the manuscript of this article we secured a machine which seems to be practically an ideal instrument for measuring tearing resistance. The instrument, which is illustrated in Figs. 2 and 3 and described in the appendix to this article, is made by the Thwing Instrument Company of Philadelphia. We refer to this instrument as machine No. 2. It is pertinent to remark that this machine is not a certain older type made by this concern and on the market for sometime. We have not had any experience with the older type. This machine No. 2 differs from all previously described instruments for measuring tearing resistance in that each single measurement of the machine determines the average tearing resistance over a considerable length of paper. On this account when measurements are made on a uniform paper, individual readings differ by only small amounts and thus the average of a very few measurements can be repeated with great exactness on a second lot of similar samples. A further advantage of the machine is the facility with which tests can be made and the simplicity of the testing itself.

Study of the tearing resistance test as we have made it with either No. 1 or No. 2 machine indicates that it is a very satisfactory method of comparison of similar samples, or of samples which differ in only one important particular. Thus it is possible to rank accurately samples from the same original lot, but differing at the time of test in moisture content, or in length of time subjected to various aging conditions. Without further evidence, however, it does not necessarily follow that two samples differing in several particulars, but giving the same tearing resistance, are equal in usefulness. Thus we might get the same tearing resistance on a sample originally of high resistance, but subjected to an aging test, as on a sample originally of poorer quality but not subjected to the aging test.

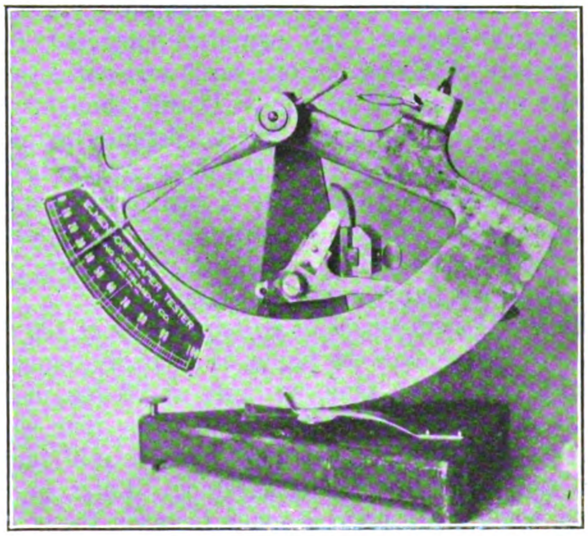

Fig. 3

Undoubtedly, the measurements of the instruments we have used are of very great value in making comparison even under such an instance as this, but conclusions to be drawn from tests of samples from different sources and under different conditions must not be considered complete or final without a further analysis of the matter.

Before describing recent tests made with the aid of a tearing resistance machine we will describe some very old tests made by one of the authors during 1905. These tests are of very considerable importance for two reasons. They constitute an important part of the basis for the present temperature rating of paper cables. Second, though they are in agreement with some other tests reported by other observers, they point to materially different conclusions from most of the other tests reported in this paper. Suggested explanation of some of the difference is given later.

In this series of tests, sealed samples of lead-covered cable were heated for a period of respectively one week and four weeks, one lot at a temperature of 100 deg. cent., and one lot at a temperature of 93 deg. The samples were submerged in a bath of melted paraffin, heated by a gas flame. The temperature was controlled by means of a thermostat (bi-metallic spring) which controlled a solenoid operating a valve controlling the gas. The thermostat was sensitive enough to respond to less than one-fifth deg. cent. When the temperature was lower than the setting of the thermostat, it closed the circuit for the solenoid causing it to open a valve so that the gas flame was strong enough to raise the temperature to the setting of the thermostat, after which the solenoid would release and reduce the gas flame to the lower limit and allow the temperature to fall.

It will be understood that, at the time of making these tests, there was not available any testing machine as good as a test of tearing with the fingers. The results of the test are however definite to a fairly satisfactory degree. The samples subjected to a temperature of 93 deg. for one week were not deteriorated by an important amount. It was thought that some change had occurred, but no definite assurance of this was found. However the deterioration in four weeks' time was so much that it was considered that we could not think of recommending operation at that temperature. The temperatures above, and throughout the paper, are in centigrade.

The samples subjected to a temperature of 100 deg. cent. for one week were found to be badly damaged, probably about the same as those at 93 deg. in four weeks. Those subjected to 100 deg. for four weeks were found "rotten." The paper was so stiff that it could not be bent without breaking. Later in this article, some comparison is made between these tests and more recent ones.

These tests were reported in sub-committee meetings of the Standardization Committee of the Insitute and, together with supporting information from other sources, are the basis of the present temperature limit of 85 deg. cent. as given in the Standards of the Institute for low-voltage paper cables. The temperature of 85 deg. was chosen as a safe amount lower than the test temperature of 93 deg. which resulted in serious injury to the insulation in four weeks.

Before discussing the effect of heat upon the mechanical properties of paper, it is well to say a word about the effect upon its composition. If paper in its natural condition is dried at say 100 deg. cent. for a short time, or at a lower temperature and under vacuum, it will lose up to nearly 10 per cent of its weight in moisture. This easily removable moisture is sometimes called "moisture of condition." If paper is exposed freely to the atmosphere, the moisture content will vary with the humidity and temperature of the air. Thus paper exposed to air in an ordinary heated room in the winter time contains very much less moisture than similar paper exposed freely to outdoor air in the winter, or to air in the summer time. Accompanying this change in moisture content, and doubtless caused by it, there are important changes in the mechanical properties of the paper, as will be shown. If the heating of the paper is continued at high temperatures for long periods of time, longer time being required at relatively lower temperatures, there is a continued and slow loss of weight of the paper and a continued change in its mechanical properties. These changes are very similar to the changes however that are undergone when only the moisture of condition is driven off.

Tests of tearing resistance of paper were made under a wide variety of conditions. Tests on several different kinds of paper were made each under several conditions. The different conditions studied include effect of moisture content and of saturation with different kinds of compound and a study to determine the part played separately by the saturation and by the drying where a sample is subjected to both drying and saturating. Aging tests were made on samples exposed to air and on samples submerged in two different kinds of compound.

The first striking fact in connection with these tests is that impregnation itself affects only very slightly the tearing resistance of the paper. The cause of the great loss of tearing strength when the sample of paper is dried and impregnated is the change in moisture content and is not due to the impregnation with compound. Tests of the tearing resistance of paper dried for a short time in oven and of similar paper dried by immersion in compound at 125 deg. showed practically the same result. Some more careful comparisons were made as follows. Paper was dessicated under vacuum and at room temperature. One lot was tested dry, one lot after saturating with "lectroseal" transformer oil, and one lot after saturation at 80 deg. cent. in the petrolatum compound which was used in the tests. The sample in transformer oil was about 10 per cent weaker than the dry sample. Samples impregnated with petrolatum compound have shown as much as 35 per cent greater strength than dessicated samples. In other cases the difference has been slight.

Another lot of paper which had not been treated and was merely exposed to air at 30 per cent humidity wa

divided into three lots. A lot which was impregnated in cold transformer oil was found to have exactly the same strength as the original sample which was not treated. Another sample was impregnated in petrolatum compound at 80 deg. cent. and was found to be 24 per cent stronger than the original sample. As four papers were grouped together during the tearing test, it was thought that adhesion between the samples might have been responsible for the increase of strength. Some of the original paper and some of the impregnated paper were tests with only a single sheet. With single sheets the impregnated paper was 18 per cent stronger than the original. Thus, perhaps a portion of the increase was due to the cause suspected.

The next striking fact to be observed is the extremely large variation in tearing resistance with change in moisture content of the paper. Thus, a given sample of untreated paper was subjected to an atmosphere of approximately 100 per cent humidity. A similar sample was subjected to a vacuum, both samples being treated at ordinary room temperatures of about 20 deg. cent. The tearing resistance of the second sample was less than 40 per cent of the first sample. Samples exposed to air of different degrees of humidity show intermediate tearing resistance.

With the paper tested and with the oils used, and for the relatively short series of tests which were made, there is an astonishingly small difference between the aging effect at a given temperature of paper submerged in oil and the paper exposed to air in an enclosed vessel, either sealed or unsealed. This is contrary to the usual understanding that the deterioration in air is much greater than under oil. However, some observers have reported the contrary, namely, that deterioration is more rapid under certain classes of oil than in air. Such differences as we have found are not entirely consistent and thus there is room for further study of the matter. In general, the tendency seems toward a higher rate of deterioration under oil than in air at high temperatures and where the periods are very short. For longer periods of time, the rate of deterioration seems to tend to be a little greater under oil, (but the difference is not of very great amount). In any comparison which we so far have made, the difference has not been greater than the difference due to perhaps five degrees variation in temperature.

The above paragraph applies specifically to a simple mixture of 80 per cent commercial petrolatum and 20 per cent commercial resin. Tests were also made with a mixture of 80 per cent commercial resin oil and 20 per cent commercial resin. Commercial differences in the ingredients do not have a very important effect upon the particular property under consideration, namely the aging of the paper. Therefore it is considered that the test with these two specific mixtures will represent fairly well the result to be expected with most of the impregnating media which are in extensive commercial use. Tests were made with similar lots of paper in the respective types of compound and at 125 deg. cent. for periods of one week and two weeks. The results indicated a greater rate of deterioration in the resin oil compound. The difference was not large and we do not consider the results conclusive, except so far as they indicate that the difference in the effect of the kind of saturating medium is not very great; not as great as would be caused by a temperature difference of 5 deg. cent.

Measurements of the aging of several different kinds of paper, were made. There is a fairly definite variation obtained with different samples of standard grades of Manila cable paper. For comparison, some Kraft paper composed of wood pulp was tested, also a sample of Bond writing paper. These last named samples were much lower in original strength, but the percentage of reduction due to the aging was of the same order of magnitude as for the Manila. The decrease in tearing resistance at 125 deg. was as great on one sample of Manila paper as would be expected with the best Manila paper at a temperature of perhaps 10 degrees higher, and for the same time. From the standpoint of aging, no paper was found better than the paper which furnished the basis for the curves in Figs. 4 and 5. Even though the deterioration of a sample of low original strength is not at a higher rate in terms of the original strength, the paper would be at all times, weaker than another sample of better original quality.

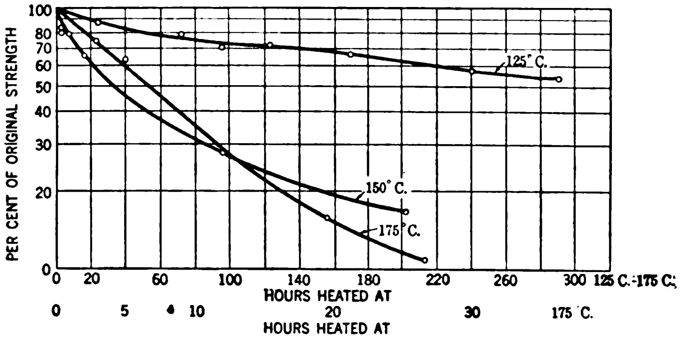

Fig. 4

In Fig. 4 are given three curves showing the loss of tearing resistance at 125, 150 and 175 degrees respectively. In the case of the 175-degree curve, the tearing resistance of the samples, tested before opportunity for reabsorption of moisture from the atmosphere, in terms of the strength of the original paper dessicated under vacuum at room temperature, is plotted as ordinates. Number of hours aged is plotted as abscissas. The tests at the other two temperatures were made on samples which had been allowed to come to equilibrium as regards moisture, in air at about 30 per cent humidity and 20 degrees temperature. The ordinate in these two cases is expressed as the tearing resistance in percentage of the original tearing resist-

ance of the paper, with it also in equilibrium as regards moisture content with atmosphere at 30 per cent humidity. As all the samples had been exposed together to the atmosphere for a long period of time the conditions were similar. Tests were made on some of these samples aged, after dessication and in comparison with dessicated but unaged original samples, and the percentage of strength based on these figures is not materially different from those plotted, in Fig. 4. For purposes such as now under consideration, values determined as for the 175-degree curve would be preferred.

From the data of the curves in Fig. 4, Fig. 5 has been constructed as showing the relation between temperature and number of hours required to produce certain definite amounts of deterioration. Each curve on

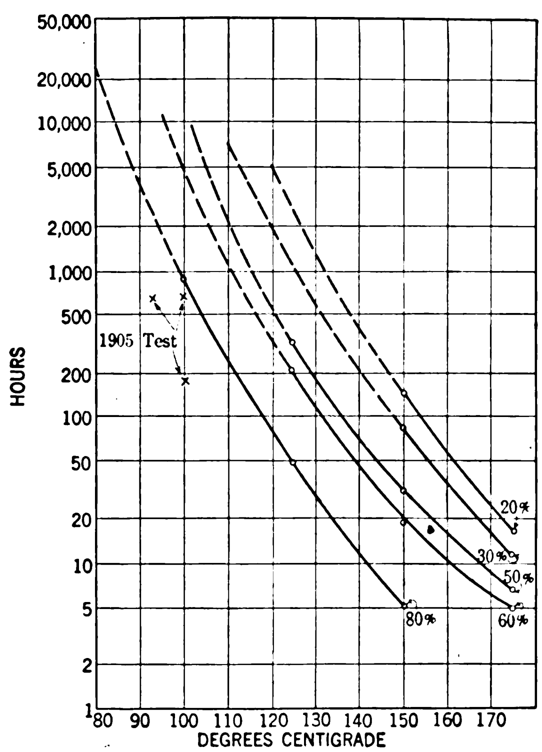

FIG. 5

Fig. 5 represents a certain definite amount of deterioration and shows the length of time required for the tearing resistance to fall to a certain percentage of the original tearing resistance. Thus, the lowest curve shows the time required to come to 80 per cent of the original tearing resistance. The three points indicated by a cross belong to another series as will be mentioned presently.

A point on one curve in Fig. 5 is given at 100 degrees. This is from a test on paper saturated in petrolatum compound and maintained at 100 deg. for 37 days.

It will be noted that the scale of time is logarithmic and covers several decades. The curves have been extrapolated at the left-hand side with the idea of estimating time required for deterioration at lower temperatures with correspondingly very long time. Of course it is recognized that extrapolation is likely to cause serious errors in conclusion and therefore these conclusions must always be interpreted with caution. If some additional points are obtained at the higher temperatures, and particularly if points are obtained at lower temperatures than those at which most of the tests were made, it will be quite reasonable to expect fair accuracy of extrapolation into the range of temperature with which we are most concerned. Even with the data as now presented, some important conclusions can be drawn.

It is interesting and important to note that the different curves approximately parallel each other. The slope of these lines is of perhaps as much importance as the actual numerical values. Thus, it will be observed that the rate of deterioration doubles for a temperature increase of about 8 deg., at temperatures near 125 deg. Within range of 100 deg. and lower, the increase of rate of deterioration with temperature is even greater. Thus, as the lower curve in the figure is drawn, the rate of deterioration is doubled in about 5 deg. increase of temperature. These rates correspond respectively to increasing the rate of deterioration tenfold in about 25 deg. and about 15 deg. respectively. That is, the rate of deterioration at 100 deg. is roughly ten times as great as at 85 deg.

As the curve is drawn, an appreciable deterioration (about 20 per cent) is shown at 85 deg. in about nine thousand hours, that is about one year. In case the extrapolation is wrong and the deterioration at 85 deg. is much lower than thereby indicated, the slope of the curve is greater and the increase in rate of deterioration with temperature is even greater than the figures named in the preceding paragraph.

On the basis of the slope of the curve as drawn, in Fig. 5, may be determined the effect of intermittent loading at high temperature. Thus the annual rate of deterioration of a cable loaded so as to produce a temperature of 100 deg. cent. for about two and one-half hours per day and a temperature much lower than 85 deg. for the rest of the day will be about the same as that of a cable loaded continuously so as to produce a temperature of 85 deg. Now it is not improbable that the rate of deterioration at 85 deg. is materially lower than as indicated in Fig. 5. If that is correct, then an intermittent load producing a temperature of 100 deg. cent. for some shorter period than two and one-half hours would be equivalent to a continuous load producing a temperature of 85 deg.

If the continuous loading produces a high temperature, followed by higher temperatures for short periods, the deterioration due to both conditions must be considered. Thus, on the basis of the specific values given in Fig. 5, the rate of deterioration of a cable having a temperature of 100 deg. for two and one-half hours per day, and of 85 deg. for the remaining time would be nearly twice as great as for a continuous temperature of 85 deg.

We may now refer again to the 1905 tests previously described. While of course, as stated, no permanent record could be kept showing the degree of deterioration of the paper in the 1905 tests, the following method of comparison was used. Samples which were aged recently and had been measured, were compared with the recollection and description of the aged paper of the old tests in an attempt to obtain some rough numerical value for the deterioration obtained in those tests. Little doubt was entertained that the sample which had been maintained at 100 deg. for four weeks, was as bad as recently tested samples, which had been reduced by aging to 30 per cent of their original tearing resistance. On this basis, the deterioration obtained at 100 deg. in the old series of tests was as great as would be expected from recent tests at 125 deg. in the same length of time. This difference in temperature is large as compared with the uncertainty of the comparison, and we may thus consider that roughly the relation just stated exists between the old and the new tests.

It is important to consider the possible causes of this large difference. It is not unlikely that part of the difference lies in the paper itself used with the two tests. There is an apparent possibility of accounting for perhaps 10 deg. of the difference in this way. The data for the curves in Fig. 5 are based largely on tests on saturated paper exposed to air; the 1905 tests were upon samples of cable saturated with resin oil and sealed in the lead cover. The apparent greater rate of deterioration obtained in recent tests on resin oil saturated samples as compared with petrolatum saturated samples, or perhaps with samples exposed to air, may account for another part of this difference. This is particularly true as there was some evidence in the recent tests of a greater rate of deterioration at temperatures lower than 125 deg. of samples saturated in compound than those exposed to air.

A further point of difference between the old tests and the new is that the old tests were made upon an actual cable sample which had undergone a certain amount of aging in the process of manufacture, whereas the recent tests were upon paper not subjected to such preliminary aging. The shape of the curves in Fig. 4 would tend to point to this fact as not helping to account for the difference, but the reverse. That is, a sample loses a greater percentage of its original strength in a period of given length after the beginning of the aging than it does in a second equal period, even with the loss of strength in the second period expressed in terms of the strength at the beginning of that period. However, in a study of the possible reasons for the different results obtained, this difference in the manner of tests should not be overlooked. We are not at all inclined to be satisfied that the three possible causes mentioned are sufficient to account for the difference between the old and the new tests.

Even after there are available sufficient experimental and laboratory data as to the degree of deterioration occurring at different temperatures and under different conditions, there still remains to be determined what is an allowable amount of deterioration from the standpoint of operation of the cable. As the deterioration is continuous and gradual and as there is no temperature at which there is a sudden change in the rate of deterioration, any definite limit to deterioration which is set will be arbitrary. We will now consider the matter of limitation, in the light of operating experience and operating demand.

It is known that cables have been in service for long periods of time and with various degrees of deterioration of the paper even up to practically complete carbonization. In most cases where such conditions existed, we believe that not a very large amount of cable has been thus affected. Thus while there are numerous individual examples of cable samples which have been found to operate successfully with a large degree of damage to the insulation, there is actually in service a comparatively small number of feet of such cable. Thus there is not any extensive record of the serviceability of cable in considerably damaged condition. Furthermore, it is probable that such cable furnishes a large proportion of the operating failures that are not due entirely to external injury, an amount of failure insignificant in comparison with the amount of such cable in service. Furthermore, such cables may fail in service from injury due to causes which would not be harmful to good cable. Though examples of this sort are cited as evidence of how far the deterioration may be carried without causing electrical failure, we do not believe that it is the policy of operating engineers to recommend operation which may be expected to produce this condition in any short term of years.

Many of the cables known to have operated successfully after severe overheating have had very liberal insulation thicknesses. This fact has an important bearing on their successful operation after being damaged. Thus if an attempt were made to standardize an operating temperature which would produce any material deterioration of the insulation it would need take into account the liberality of insulation in proportion to the operating conditions.

One viewpoint of the operating companies is evidenced by the attitude of some of them with regard to cable specifications. We will refer particularly to the recently published specification of the N. E. L. A. Underground Systems Committee, which was produced after extensive conference with many engineers representing different parts of the industry. In the discussion preliminary to that specification, the operating engineers emphasized very strongly the importance of the ability of a cable to withstand installation under severe conditions, removal from the duct line if necessary and reinstallation, again under severe conditions. It is not to be thought that extreme sacrifices

would be made to insure the ability to reinstall especially under severe conditions, but we know that it was emphasized as an important matter.

In view of this attitude, it would seem unreasonable for this Institute to standardize operating conditions which would materially reduce the serviceability of cables from this standpoint. It is proper however, for the Institute to recognize that operating conditions will sometimes exist which will make it a matter of economy and of good engineering to operate at temperatures expected to produce rapid deterioration and probable short life. It may be cheaper and better practise to replace cable at intervals when necessary than to put into service from the beginning, a much greater amount of cable. Or it may pay to load a cable to such an extent that there will be rapid deterioration, though reasonably long life will be expected provided it is not moved or mechanically disturbed. A single example of such a condition is where initial temperatures are very high and thus where a relatively slight increase of temperature would permit a very great increase of current rating. This subject is not for detailed consideration at this time, but is a matter which must be decided by each cable user on the basis of ultimate economy. The data furnished at this symposium regarding deterioration at higher than ordinary working temperatures, will be of great value in the analysis of such special cases.

As a definite suggestion in line with the above discussion, it is submitted that the Committee assign a temperature limit which may be expected to produce a reduction of 20 per cent of the original tearing resistance of the paper after a period of say five years' time. Supplementing this, higher temperatures may be named which will produce the same annual rate of deterioration if the temperatures are maintained for a certain corresponding number of hours per year.

This specific suggestion, together with the specific data in Fig. 5 will lead to the following temperature limits:

For continuously maintained temperature	78 degrees
For maximum temperature maintained five hours per day, temperature during remaining part of day low	85 degrees
For maximum temperature maintained two and one-half hours per day, temperature during remaining part of day low	90 degrees
For maximum temperature maintained one-half hour per day, temperature during remaining part of day low	100 degrees

It is to be expected that there will be available to the Committee additional information which will confirm or modify these suggested values.

It has been remarked that cable failures have resulted from the motion of cables due to contraction and expansion with variation of temperature, resulting in cracked sheath and ultimately in failure due to entrance of moisture. It has been reported that satisfactory means for preventing this difficulty have been found. Cable users should be cautioned in regard to this matter and should be informed as to the preventative methods.

Where data are available concerning any considerable length of cable which has been severely damaged in commercial service by overheating, it will be of particular value if any unusual phenomena are reported. For example, in tests made by one of the authors in 1913, a 100-ft. length of cable was heated to a temperature such as to produce rapid deterioration. It was found that a large amount of gas escaped from the ends which were at first unsealed. Accordingly, terminals were attached to the ends so as to prevent the escape of the gas, and a steam gage was attached so as to register the pressure inside the sheath. This pressure reached a value of about 100 lb. per sq. in. at which pressure the sheath burst and the pressure was relieved by the forcing out through the hole of a large amount of compound and gas.

In the recent series of tests, where samples were sealed in lead tubes, some difficulty was experienced in maintaining the seal tight, and there was considerable evidence of internal pressure. This information points to a possible limitation of amount of allowable deterioration quite aside from the changing properties of the paper itself.

It is worthy of particular note that, for ordinary conditions, much more is to be lost by operating at a temperature a few degrees too high than by operating at a few degrees lower than the maximum allowable temperature. For example, based on an earth temperature of 20 deg. and an operating temperature of 85 deg. a change of 5 deg. in the operating temperature will be produced by a change of current rating of only 4 per cent under ordinary installation conditions. But an increase of 5 deg. above the correct limiting temperature will result in a shortening of the life by one-half. Therefore, an accurate knowledge of actual temperatures of cables is a requisite for obtaining maximum performance without danger of material reduction in life of the cables.

Without a margin of safety in the temperature rating, the importance of accurate knowledge of temperature conditions or proper allowance for want of this knowledge is of fundamental importance. Neglect of this will lead to cable damage far more costly than a sacrifice of carrying capacity due to operating at even less than the safe maximum. Thus in rating cables for current it is important to leave whatever margin is necessary to insure that uncertainty in knowledge of conditions does not cause an excess of temperature.

Acknowledgment is made to Mr. F. E. Coxe for valued work during the series of tests just concluded and to Mr. N. C. Davis for the investigation of the "pop-tester."

APPENDIX

Machine No. 1 is essentially a very light vertical tension testing machine having a maximum reading, or automatic recorder. The scale was read as centimeters deflection but a calibration was made in grams by hanging weights from the dynamometer spring.

Standard samples were prepared for test as follows. Strips of paper usually one inch wide were cut in lengths of 7¼ in. Five holes ¼ in. in diameter were punched along the center line of the paper and about ⅝ in. between centers, the first hole being about ⅝ in. from one end. From the other end a cut was made with scissors to within ¼ in. of the last hole. From the end of that hole to within ¼ in. of the next a cut was made with a razor blade. This was repeated for each hole.

Test was made after clamping the free ends on each side of the scissors cut in the jaws of the testing machine. The maximum force required to tear from the cut into the next hole was read for each of the five holes. The average of fifteen readings taken on three samples of paper constituted a single test.

Other forms of test sample were used at an earlier date but the above was especially useful as giving a considerable number of tests so as to give a good average within a small sample and in a reasonable time.

In the description of the No. 2 machine, we quote largely from a statement by the maker of the machine.

The machine is known by the maker as the "Elmendorf Paper Tester." It was finally perfected in the Forest Products Laboratory of the United States Forest Service. It is the understanding of the writers however that the makers of the machine have added some improvement since making the statement which we quote in the previous sentence, and that these improvements are embodied in the machine with which we have worked.

The testing machine simulates the action obtained by one method of hand testing on paper when a sample piece of paper is torn between the fingers in order to "sense" the average tearing force. The instrument consists essentially of a weighted pendulum which, in swinging from a predetermined height, tears the sample to be tested and indicates the tearing strength of the paper by the amount its swing is retarded.

Briefly, the machine operates as follows. A certain number of samples of the paper to be tested (generally four in our tests) are selected, each 6 cm. long and 3 or 4 cm. wide. (Our tests were made on samples 1 in. wide). The samples are then set in the machine and held in the clamp as shown in Fig. 2. A knife on the machine is made to cut a slit in the paper, giving a start for the tear. The cut is a definite distance of 2 cm. thus giving a distance of 4 cm. for the tear.

The pendulum is then allowed to fall and as it does so, it tears the paper as indicated in Fig. 3. As the tearing action proceeds, the motion of the pendulum is retarded by an amount proportional to the work done in tearing the paper. For each grade of paper tested, the pendulum will therefore rise to a different height on the right. The lighter the paper and the less work required to tear it, the higher the pendulum will rise, and the heavier the paper, the less the pendulum will rise. The greatest height to which the pendulum rises on the right is registered by a pointer and can be read when the pendulum comes to rest. This reading is a measure of the work done in overcoming the tearing strength of the paper through the length in which it was torn. It is proportional to the average tearing strength of the paper when the number of papers and the distance torn are constant.

In using machine No. 2 for measuring tearing resistance, usually four pieces of paper were tested simultaneously and the total length of the tear was 4 cm. The individual readings thus gave the average resistance for the four papers. Most of the data recorded are the average of four individual measurements. As this gives an average of the tearing resistance of 64 cm. of paper, it may be expected that the results will be capable of very exact duplication for uniform paper. This is further illustrated by the following. On twenty different measurements, each the average of four or five individual tests, the numerical differences between individual measurements and the average of all were taken. This difference was expressed in per cent for each set of readings. The average of these average differences of twenty tests was 4 per cent, the maximum was 11 per cent. This was on a very brittle (aged) sample. No other difference exceeded 8 per cent. It seems reasonable therefore to expect that the error of the measurement of any sample taken should seldom exceed 5 per cent and that the probable error of any result did not exceed about 2 per cent.

However, it has been found that samples tested on different days under conditions considered identical have given differences of as much as 20 per cent. The difference is attributed to variation of paper at different parts of a roll which was evidently not entirely uniform in tearing resistance. Of course, wide variations are to be expected if moisture content is allowed to vary and it is very hard to keep this under control. The variation of 20 per cent was found however in the case of two sets of samples which were dessicated by drying in a vacuum at a temperature of about 20 deg. cent. It is not known at this time just how much influence small changes of temperature or small changes in the residual pressure in a vacuum chamber may have affected these results.

With the No. 1 machine for measuring tearing resistance, we considered the limit of probable error of the measurement of the actual samples under test, to be about 10 per cent.

Superpower and its Relation to Industry

BY HENRY FLOOD, JR.

Engineer-Secretary Superpower Survey

THE SUPERPOWER idea is not new. It is only the expansion of present central station practise greater in magnitude, but not more complex in structure. It is the replacement of small scale by quantity production.

While great progress has been made in reducing power costs and in conserving fuel by the central station systems of this country, there is still much that can and must be done along these lines. The recent war made many thinking men realize that notwithstanding the improvements that had come into operation during the last ten years, there was still a vast waste both of fuel and money going on in this country in the production of power, and some of these men who had a greater visionary power further realized that these very wastes would become a tremendous handicap to us in the competition for the world's markets which has followed after the war.

These wastes have been recognized and have been frequently discussed, but to Mr. William S. Murray the credit must be given for bringing the country from out of the period of discussion into that of positive action.

The North Atlantic seaboard was the region selected for the first Superpower Survey, and the reason for such a selection being made is not a hard one to find. This section of the country, which is known popularly as the superpower region, embraces the territory along the North Atlantic seaboard from about Portsmouth, New Hampshire, to Washington, D. C., and extends inland on an average of about 150 miles. Geographically, it is a very small portion of the country, as it contains only about 2 per cent of the total land area. From the standpoint of population it is important, as about 22 per cent of our inhabitants live within its borders. According to the recent census, 75 per cent of the people in those states of which the superpower region is a part, live in cities and towns, while for the balance of the country only about 41 per cent are city dwellers. But most of all its importance to the country's needs stands forth from its industrial activity, as nearly 40 per cent of the total value of manufactured products come from this region, and about 35 per cent of all the country's power is generated within its boundaries.

This industrial supremacy can easily be visualized from the fact that one out of every eight persons living therein is an industrial worker, while for the balance of the country we find only one out of every 25 persons so employed. New England is even more intensely developed from the industrial view-point, as there one out of every 6.4 persons is a wage earner in factories.[1]

Another measure of the industrial activity of the superpower region is shown by the output of manufacturing products, which was $314 per capita in 1904, and $390 per capita in 1914, while the balance of the United States produced manufactured articles to the value of only $113 per capita in 1904, and only $190 per capita in 1914.

This intense industrial development results in a very large demand for power to operate the industries and to provide the transportation both for the raw materials into the region and for the finished products to the peoples living without the region; hence it was logical to select this region as the one in which could best be shown the merits of a regional power system.

The history of our power development has been truly remarkable when compared with that of other countries. It has grown from a period where we had practically nothing but small isolated plants, to the present era where we have large central station companies serving extensive areas and population. However, today these companies are for the most part segregated and have either no connection with their neighbors or only very light connections where the interchange of power is principally for breakdown purposes. It is very seldom that we find these connections between the central station companies such that power may be interchanged with a view toward a more economical operation of the participating companies.

Superpower goes a step in advance. It provides a regional system through which all of the large load centers within its boundaries will be linked together by means of heavy trunk transmission lines capable of carrying sufficient power so that each power plant can be operated in the manner necessary to get the greatest resultant economy to the entire region.

It provides for the construction of large base load steam electric plants located at tide-water, on inland rivers, or in the coal mining territory, as conditions may warrant.

It makes possible the construction of hydroelectric developments at potential water power sites, the development of which is not now advisable with the conditions existing on our present power systems.

Superpower does not consider the abandonment of present central station systems. They are the nucleus about which a superpower system would be built up. While the older and more expensive plants will have to be gradually abandoned, the larger

Presented at the Worcester Section Meeting, A. I. E. E., Feb. 2, 1921.

1. Information derived from U. S. Census reports.

and more efficient plants will become an integral part of a regional system for furnishing power.

Superpower visualized is but a large power reservoir into which will be fed the output of the more efficient existing plants, the proposed new base load steam electric stations, and the hydroelectric stations; and from which the power to supply the industrial, the railroad and domestic requirements of the various load centers will be tapped where and when needed.

As great as are the power requirements of the region today they are small compared with those of tomorrow. The unassociated total power requirements have increased from about 15,000,000,000 kilowatt-hours in 1910 to about 27,000,000,000 kilowatt-hours in 1920, with a corresponding increase in machine capacity of from 8,600,000 kilowatts to approximately 14,800,000 kilowatts.

It is estimated that the power growth for the next decade will increase the total energy requirement to about 50,000,000,000 kilowatt-hours, and assuming the superpower system to be in operation, about 18,700,000 kilowatts of machine capacity will be required to satisfy this load.

Of these above power requirements electric public utilities furnished in 1920 about 12,000,000,000 kilowatt-hours with a machine capacity of 4,000,000 kilowatts, and it is predicated that by superpower operation the power to be furnished from central supply sources will grow to about 36,000,000,000 kilowatt-hours by 1930, and will require a machine capacity in the neighborhood of 9,000,000 kilowatts.

These estimates which are conservative, call for 5,000,000 kilowatts additional power plant capacity in the central supply systems during the next ten years, an increase of 125 per cent over that which we now have in existence.

In making these preliminary estimates, consideration has been given to the fact that part of the manufacturing industry today receives its energy directly by water power, and further that it will be undoubtedly found unprofitable to take over to a superpower system certain isolated plants in manufacturing industry which have use for large amounts of steam for process and heating work. Furthermore, it is realized that only a certain amount of the track mileage of the heavy traction railroads will have traffic sufficient to justify electrification, so that only those portions of the railroads have been included which can profitably be electrified.

In manufacturing industry the estimated power requirement of 1920 was placed at 12,400,000,000 kilowatt-hours, and it is estimated that the central station systems supply about 2,750,000,000 kilowatt-hours of the total requirement. By 1930 it is conservatively estimated that the total power load of manufacturing industry will increase to about 19,000,000,000 kilowatt-hours, and that of this total, superpower can economically furnish at least 10,000,000,000 kilowatt-hours, or slightly over 50 per cent of the total. While making these load estimates it has been realized that there are certain possibilities of the future, such as the extensive use of electricity for furnace work and heating. What growth will be contributed by any such developments is purely conjectural—accordingly it has not been included.

The region supports 36,000 track miles of heavy traction railroad system. Of this it is estimated that from about 6000 to 8000 track miles can be justified for immediate electrification. The present requirements of the electrified portions of heavy traction railroads are about 500,000 kilowatt-hours per year, and it is estimated that the power requirements of the electrified portions will grow to about 6,000,000,000 kilowatt-hours by 1930, considering only those portions of the railroads where electrification can be justified either through the savings effected or by the gain in increased capacity for traffic.

One of the prime effects of a regional system would be the better utilization of our nation's fuel supply.

Few persons realize that of our total coal resources only about 16 per cent lie in the Eastern province, that is within easy freight transportation distance of our North Atlantic Seaboard; and furthermore, I believe fewer people appreciate that out of the total coal mined to date about 75 per cent has been withdrawn from the coal fields lying within this province.[2]

While considering that these particular coal fields even when supplying the greater part of the country's coal requirements still have many years of existence, we cannot ignore the fact that the comparatively rapid depletion of this field as compared to the others is fast working a hardship on this paticular section of the country through the agency of advancing coal prices, brought about by the exhaustion of the higher grade and more cheaply mined coal seams within this particular province. That coal will be very much cheaper for extended periods than it is at the present time seems hardly likely in view of these conditions; in fact, all of the evidence points to just the reverse.

The coal user seldom decides his policy of coal utilization from the standpoint of national conservation, but rather upon what the cost of power will be to himself. The relatively higher coal prices that have existed for the past four years have had their effect through making it essential for the coal user to conserve his coal in order to keep his costs down.

From the studies made to date by the Superpower Survey, it is indicated that the central station systems within the region paid an average of about \$5.40 per net ton for bituminous coal delivered. The engineers of the survey have made a very careful study as to what the probable average cost of bituminous coal will be during the ten-year period from 1920 to 1930, and as a result of their consultation with the recognized

2. Data from U. S. Geological Survey, Professional Paper 100-A.

authorities on the subject of bituminous coal, they have come to the conclusion that the average cost of coal at the mine for that period will be higher than that which was in force in 1919, and that the freight will probably not vary greatly from the present rates, which are 40 per cent in excess of those paid in 1919.

Had superpower been in operation in 1920 a saving of about 30,000,000 tons of coal having a value of about $162,000,000 could have been effected, through its economies over the present performance of central stations, steam locomotives and isolated manufacturing plants, and by 1930 the superpower system should effect a saving of 53,000,000 tons per annum with a value of $286,200,000 when compared with present practise.

Despite the estimated savings given above, the load growth of this particular region is such that by 1930 at least 14 per cent more coal than is now being used for power production purposes will be required to take care of a superpower system, and the other power production facilities that would be left in the region. The argument has often been advanced that a superpower system would have a very serious effect upon the railroads, of making idle the vast investment in equipment through the removal of the coal haulage from their lines, but these figures show that this fear is absolutely unwarranted.

With regard to coal, the superpower offers also another great advantage. It will be the greatest stabilizer of the coal industry through large coal storage areas at each of its base plants, thus placing a more uniform demand for coal upon the mining sections. Those of you who are familiar with some of the elements of cost of coal mining will appreciate the importance to the coal mining industry of any such agency.

The war brought about a number of changes in our power practise. The cost of power producing equipment went up and deliveries were long delayed. The price of coal rose rapidly and not only was it scarce but often great annoyance was encountered in obtaining it. The country was calling for production, and then more production, and as a result of these contributory causes the manufacturer turned to the central station for his power requirements as never before. He accepted central station power and devoted the money he would have spent in building and operating his own power plants to the actual producing of his product.

The war, furthermore, has changed the economic position of the country. Previous to it we had gone to Europe for large amounts of money to develop our vast natural resources, and consequently we were in debt to her. The war reversed this position. Not only was it necessary for us to liquidate our debt to Europe, but in addition we found it necessary to advance her funds so that today we are Europe's creditor to the extent of about ten billion dollars.

It is conceded by our ablest financiers that this debt must be paid largely through the agency of goods rather than gold, and our own industry therefore will be thrown into direct competition in the home markets with nations employing cheap labor.

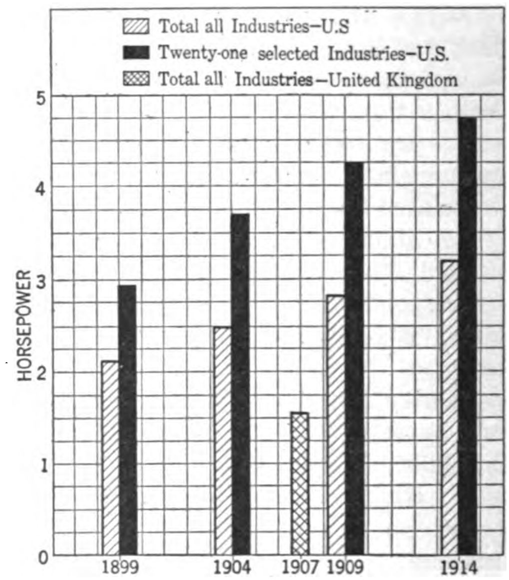

Fig. 1—Horse Power per Wage Earner in Manufacturing Industries in United States

One further effect of the war has been that our industrial production facilities have been increased so that their output cannot be absorbed by our home markets if all of their facilities are to be kept employed. The ratio of our exports of manufactured products to raw materials was very much larger for 1920 than

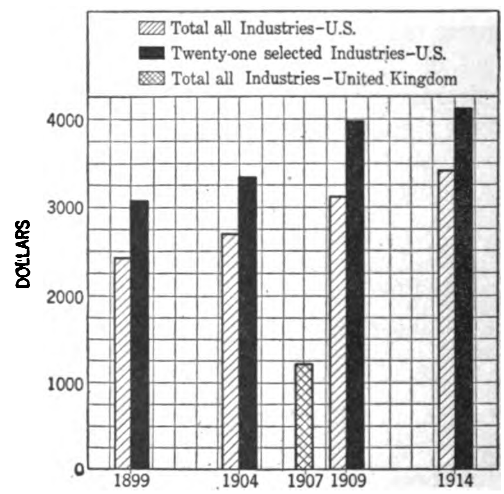

Fig. 2—Value of Products per Wage Earner in Manufacturing Industries in United States

in any pre-war year, and this is as it should be, for the exports of manufactured articles represent the employment of more of our labor at home. However, it brings us face to face with competition against the cheap labor of the rest of the world, and to maintain our position as leaders in the world's markets, it is necessary that we make our more expensive man power

cheaper than that of the balance of the world through the agency of added machine power.

In the decade between 1904 and 1914 our machine power per industrial worker increased from 2.5 h. p. to 3.2 h. p., and at the present time it is estimated to be over 3.5 h. p. In 1907 Great Britain used 1.55 h. p. per wage earner. During the same decade the value of products per wage earner in this country increased from $2700 per annum to $3430 per annum, while Great Britain in 1907 produced manufactured products to the value of only $1220 per annum per industrial worker. The relation between machine power and the output per wage earner is thus strikingly brought out, and on its face shows one of the reasons for our successful competition with the cheap labor of Europe.

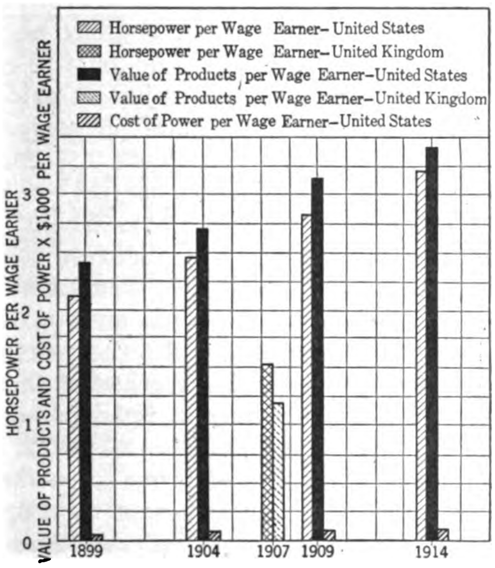

Fig. 3—Horse Power, Value of Products and Cost of Power per Wage Earner in Manufacturing Industries in United States

The superpower region is comparable to England inasmuch as both may be considered finishing shops. The superpower region contains 355 classified types of industries, of which 36 use 77½ per cent of the total power and 76 per cent of the total coal. Complete records are available for only 21 of the 36 industries, but these records disclose the fact that in 1904 these 21 industries used 3.7 h. p. per wage earner, and in 1914, 4.7 h. p. per wage earner. The corresponding value of products per annum per wage earner was $3340 in 1904, and $4135 in 1914.[3]

The foreign nations who are our competitors have recognized that the weakness in their industrial system is the lack of adequate machine power facilities, and they are feverishly working to correct this situation.

England in 1918 undertook a study of its power conditions, and as a result of the reports made by the Committee on Electricity to the Board of Trade there has been set up a definite power policy under governmental supervision, by means of which she hopes to bring her power facilities to a parity with our own. The British Isles have been divided into thirteen natural power districts under the authority of a Board of Electricity Commissioners, which has the power to direct the character and magnitude of all future electrical generating or transmission facilities, whether they be in central supply service or in isolated manufacturing plants. It is interesting to note that in the report of the Committee on Electricity to the Board of Trade, it is stated, "Investigations have shown that in the United States of America the amount of power used in industries expressed in terms of the number of operatives employed, is greater than in this country. In practically all of our industries, the h. p. per operative could be increased with advantage both to the capital and to labor, as is shown by the results obtained in the United States of America where both the net horse power per operative employed and the standard rates of wages are higher."

While the form of centralized control adopted by England will do much in furnishing her with an adequate and standardized power supply, the initiative in this country should come from the private interests rather than through governmental control or ownership, particularly in view of our recent experiences with such control or ownership.

Switzerland is taking active steps to make available more power for her industries, while Holland, Italy, and France are doing likewise.

In Germany, an extensive scheme, one in fact comparable to our proposed superpower system, is actually being constructed and placed in operation. The German plan provides for very large plants located at the coal mines and calls for the conversion of as much of the coal as is possible directly into electrical energy. It further provides for the organization of the different industries such as the textiles, the chemical industries, and others into associations which will negotiate their power requirements and prorate the use of the various individual plants. The plan is one of copartnership between private enterprise and the Government, and takes into consideration, giving capital an incentive for good management and for the rapid development of the coal mines to provide additional electrical energy. The central idea back of the scheme is to provide adequate and cheap power for the manufacture of goods intended for export.

If we are to successfully compete with these European countries having cheap labor, who have in addition recognized the value of mechanical power, we dare not stop at any figure of power utilization in our factories of 3½ h. p. per wage earner, but we must keep the differential between the machine power used in this country and that abroad at least equal to what it is today.

3. Derived from U. S. Census Bureau Reports.

The cost of power is a small proportion of the total cost of producing a manufactured article, and when this is considered with the facts we have just brought out it is very evident that the average manufacturer can obtain far bigger returns by improving the application of power with reference to increased production than he can by creating economies in the cost of power generated by himself.

Superpower recognizes the fact that if our industry is to compete in the world's markets, power in unlimited quantity must be made available to industry; it recognizes that the quality of service is of paramount importance, and therefore in laying out the tentative system one of substantially heavier construction than has ever been used in this country is being considered. It takes into consideration the fact that industrial success is dependent to a large degree upon transportation, and it provides the means for the increase of transportation to satisfy industrial demands through the electrification of those portions of our heavy traction railroad systems where the traffic density is such that electrification will either create a saving in the cost of operation, or create additional traffic capacity through its ability to handle the traffic more rapidly.

The regional power system advocated by Mr. Murray is basically sound. That large savings will accrue from it is evidenced by the savings already effected through the extension of our central station structure.

These savings of both money and fuel accrue from a number of causes. The regional system permits advantage to be taken of the diversity between the peak loads of the several districts, and allows the use of joint reserve equipment in place of the segregated reserves to much greater magnitude now required.

Through industry and the railroads the saving is brought about by quantity production displacing small scale production, and further by the ability of the regional system to take over their loads having an inherent load factor of not over 15 per cent, and by so doing raise the regional system's load factor to the magnitude of 50 per cent.

The pooling of the large part of the power in the region has a beneficial effect on the cost of both steam-electric and hydroelectric power, as it permits the use of highly efficient base load steam-electric plants operating at very high-capacity factors, a condition which cannot be obtained except on the very largest of our present electric utility systems together with the use of hydroelectric power for carrying peak load.

As is well-known the rivers in the eastern portion of the United States are subject to great variation in flow, and few of them are adapted to the operation of base load power. Their development has heretofore been retarded by the very fact that no such power reservoir as that proposed in the superpower system has been available for their output, and the creation of such a reservoir will bring the opportunity for the development of these potential water powers.

In conducting its study, the Superpower Survey has recognized as a fundamental principle that the franchise rights and investments of the existing electric public utilities must be respected and safeguarded. The function of a superpower system is to furnish the interlinking system only and to provide such generating stations, either steam-electric or hydroelectric, as can be justified from the standpoint of a lower production cost only. Its operations must cease where those of the electric public utilities begin, that is at the buses of the principal load centers.

It is very evident, particularly in the earlier stages of a superpower development, that it will be more economical for such a system to receive energy from the newer and more efficient existing central station plants where such energy can be obtained above their own requirements, than it would be for it to construct its own plants. Per contra, it is just as evident that certain of the older and more expensive plants must be abandoned, in order to reach the lowest cost of power and the greatest fuel conservation, but the replacement of these plants should not take place until the margin of saving between superpower and power of the abandoned plant is sufficient to allow for the abandoned plant's gradual amortization over a period of years out of the savings so effected. It is only by such a method of the gradual retirement of capital, that the interests of present investors can be protected.

In this connection, and of prime importance, will be the presentation in the report of the Superpower Survey of a chronology in the order of their requirement of the first and following locations of superpower stations and their attendant transmission lines. Data already analyzed indicate the immediate size and location of stations, and from this start, which will be financially self-supporting, there will be developed the extension of the system into its whole.

The principles that have governed the expansion of our city and territorial power system are entirely applicable, only in a higher degree of magnitude, to the regional system for the superpower zone. The size of power producing units and attainable voltages are such that it is no longer required that these units be placed side by side, joined by a common bus under one roof, but may be made to come into intimate relation with each other although separated 300 miles; and vast as the superpower system may seem, such a visualization of it will, I believe, serve both to simplify its aspect as well as to show that a regional situation must be met by a regional plant.

There are many phases of the problem with which the Superpower Survey is dealing, which are equal in their importance to the establishment of the physical possibility of such a scheme, and these questions dealing with the legal and financial aspects and inter-

corporate relations are being given serious consideration by the Advisory Board and its sub-committees, composed of the most able and highly respected men in the United States in their several capacities.

Industry is represented upon this Advisory Board by Mr. Magnus W. Alexander, Managing Director of the National Industrial Conference Board, and it is unnecessary to tell you his qualifications for this position as they are nationally known.

The Engineering Staff and the Advisory Board both have from the inception of the work appreciated its tremendous importance to the country, and they have felt, therefore, that even with the caliber of the men associated with the work it was very necessary to call into consultation the country's best talent, so that the report when made, will represent not alone the findings of those engaged in its actual formulation, but will have behind it the weight of the advice of the country's most highly developed experts in engineering, law, and finance.

The least that the report of the Superpower Survey can do is to show clearly what the trend has been for the past ten years in the electrical power field of this region, and what may be expected and must be provided for in the next decade. What is more probable however, is that its report can be used as the basis of a national power policy, and for the particular region studied that an actual form of corporate procedure can be set up for the accomplishment of the plan and the realization of the benefits to be derivedfrom it.

Private interests must recognize the necessity for adequate and economical power development if they are to avoid the governmental influence that has occurred in Great Britain. When Mr. Murray's report is made—and if the conclusion is that the utilities, industry and the people as a whole will benefit by such unification as is the basis of the report—then the private interests must act—quickly and effectively—to retain the control of the utilities which has been theirs in the past through their aggressiveness and good management.

SOME ELEMENTS OF THE ELECTRON THEORY OF MATTER

Abstract of an address by Professor Vladimir Karapetoff of Cornell University*

Prof. Karapetoff emphasized the point that it is easy enough to evolve a theory that would explain various known facts *qualitatively*. The real difficulty consists in assigning such numerical values to the various parts of the assumed mechanism that widely differing facts be satisfactorily explained *quantitatively*, without contradictions. A mathematical analysis of experiments is necessary in order to derive such numercial values. Those who set out to become familiar with the electron theory usually get discouraged not because the hypotheses involved are too complicated, or the leading experiments too obtuse, but because the mathematics which accompany the treatment seem too advanced or not convincing. For this reason the speaker devoted his lecture to the elucidation of some of the mathematical methods used in modern electron theory.

According to this theory an electron is an elementary particle charged with negative electricity, or actually consisting of negative electricity. Atoms of matter are supposed to be built up of such electrons and of a positively charged nucleus in the center. An atom in its structure is similar to a solar system. First of all the speaker showed how the charge on an electron may be computed to a high degree of precision from the well-known "oil-drop" experiments of Professor Millikan. Then he showed how the speed and the ratio of charge to mass of an electron may be determined from J. J. Thomson's experiments in a cathode-ray tube. The radius of the electron is then readily computed from these data, using ordinary laws of mechanics and electromagnetism.

Next the speaker touched upon the mathematical theory of "chaos", when electrons or molecules, or both, fill an enclosed space. Using the theory of probabilities he deduced Maxwell's law of distribution of velocities of molecules and electrons, which law serves as a basis for many important computations in the electron theory. Brownian movements in gases were treated next and Einstein's fundamental formula was deduced from which the number of molecules in a cubic centimeter of gas can be computed from observation of microscopic irregular motions of a light suspended particle in a gas.

Finally Professor Karapetoff spoke of what he called one of the triumphs of the electron theory, namely Bohr's model of an atom and his theoretical confirmation of the frequencies of the lines of hydrogen spectra from a nebula, to within one tenth of one per cent. "The Electron theory is bound to play a more and more important part not only in physics and chemistry, but in electrical engineering as well. Theories will change, but it is time for younger engineers and physicists to become familiar with the fundamental in controvertible experiments and with the principal methods of mathematical analysis of electronic motions. Otherwise these men will soon be hopelessly out of date."

*Delivered before the Pittsburgh Section of the A. I. E. E., February 8, 1921.

MIRRORS FOR OSCILLOGRAPHS

Recently the Bureau of Standards, Washington, D. C., has developed a new method for producing very small and light mirrors for use on oscillographs. Sometime ago an attempt was made to produce these mirrors from aluminum, polishing the metal in the usual way. However, it was found that the metal was too soft to be satisfactorily polished and some other means had to be devised which would give a better and at the same time as light a mirror. The process, as finally worked out, consists in pressing the aluminum between two optically flat steel dies. The mirrors thus made are highly polished with the surfaces sufficiently plane to produce satisfactory images of the spot of light.

Present-Day Practise Limitations of Oil Circuit Breakers

By the Sub-Committee on Oil Circuit Breakers and Switches of the Protective Devices Committee*

H. R. WOODROW, Chairman
Stone & Webster, Inc., Boston

IN ORDER to summarize the present-day indefinite operating requirements and limitations of oil circuit breakers, the A. I. E. E. (Protective Devices Committee), N. E. L. A. (Apparatus Committee) and Electric Power Club (Power Switchboard and Oil Circuit Breaker Section) cooperated in sending out a joint questionnaire for oil circuit breaker data to the larger operating companies. The response to this questionnaire was prompt and rather complete, which is an indication of the interest taken by the operating companies.

This subject has been given careful consideration in the past and several papers have been presented, and still there remains much research work to adequately determine the proper limitations of design and application. To this end it is suggested that operating companies add to their systems, equipment which will register essential transients that can not be registered on the usual quota of indicating and recording meters. On account of lack of generator capacity and operating complications, it has been impossible to test oil circuit breakers to any great extent to determine their limiting rupture points and consequently the circuit breaker of today is based largely on deductions from the results of system trouble, the conditions of which are usually of rather indefinite nature. At the present time, however, the operating companies are showing an increasing willingness to cooperate with the manufacturer in the development of oil circuit breakers by allowing constructive tests to be made on the generating equipment of their systems.

We feel that the results of this cooperation will lead to a marked improvement in that it will make possible the elimination or correction of a number of minor defects, which in the few tests that have been made have been shown to be a factor in causing previous failures.

In the paper on "Rating and Selection of Oil Circuit Breakers", by Messrs. Hewlett, Mahoney and Burnham, presented before the A. I. E. E. in February 1918, the basis for the present day manufacturers' standards was outlined, and we propose to summarize in this report the operating companies' viewpoints of these standards, as brought out in the replies to these questionnaire, together with recommended revisions.

The general requirements for oil circuit breaker specifications have been classified as follows: first, rated voltage second, rated continuous current-carrying capacity; third, rated momentary current carrying capacity; and fourth, rated interrupting capacity.

Rated Voltage

Insulating requirements are fairly well established, but, nevertheless, there have been some failures due to the inability of the oil circuit breaker to withstand voltages encountered under operating conditions. Some of these failures have resulted in serious explosions, due to the vaporizing of the oil and the igniting of this explosive gas mixture; some have been caused by bushing trouble and others by breakdown of the insulating material.

It would seem that the present test requirements, as specified by the A. I. E. E. standards, of 2. 25 times operating voltage plus 2000 volts may not be severe enough for the larger moderate-voltage system. Some operating companies are using oil circuit breakers of higher voltage ratings in order to secure better factors of safety; and further consideration should be given to raise the present voltage test requirements. These tests are usually made under clean, dry conditions, whereas the circuit breaker is subjected to abnormal conditions at the time of its operation when the breaker is apt to be covered with moisture and often dirt, in the case of outdoor breakers; and particularly with breakers in cell structures it is apt to be surrounded by gas which does not have the same insulating qualities as dry air. This condition also holds for the inside of the breaker where under test the insulating medium is dry, clean oil having a high dielectric strength. Moisture is found in the oil of any breaker after it has been in operation a short time and there is a certain amount of deterioration of the oil which is accelerated every time the breaker ruptures short-circuit currents.

A breaker is also apt to have impressed across its terminals potentials considerably above the normal voltage of the circuit. As an illustration, the disconnection of a circuit with synchronous equipment at both sides of the terminals allows the two systems thus sepa-

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rated to drop out of step and at times will be put in opposite phase relation, thereby producing double voltage across the contacts.

We would suggest that the oil circuit breaker standard potential tests be investigated with an idea of increasing this test value. These tests should be made between all live parts to ground and between phases under conditions for minimum clearances.

Rated Continuous Current-Carrying Capacity

There has been little trouble reported of oil circuit breakers overheating under normal operation, although the reports indicate that some operating companies order oil circuit breakers with current rating above their requirements. This has probably been a wise policy as it allows a greater margin of temperature rise in the breaker under short-circuit conditions and a greater margin of safety. Some trouble of overheating has been reported which has been caused by poor workmanship, such as poor alignments of contacts. It would be a great help if the contacts were made for greater ease and permanency of adjustment.

In order to reduce the maximum temperature and to prevent accumulation of explosive mixtures in cell compartments which has given some trouble, we would recommend that careful consideration be given to ventilation of compartments cautioning at the same time against ventilation which would allow gas from one compartment entering an adjacent cell. One company has found it desirable to carry the ventilation from each tank to the outside of the building.

Rated Momentary Current-Carrying Capacity

Trouble has been experienced by some of the larger operating companies through the failure of oil circuit breakers to carry heavy short-circuit currents for the period of time required to open the circuit and in some cases of the inability of the current-carrying parts to withstand the strain produced by the electromagnetic forces. We are very fortunate in having the accompanying paper by Mr. Torchio which outlines the results of a very extensive series of tests along these lines, showing very conclusively certain weaknesses in oil circuit breakers from this standpoint. The principal weaknesses brought out in these tests have now been corrected.

It is recommended that all oil circuit breakers be given a short-circuit current rating for a period of say both one and five seconds which should be at least equal to the interrupting capacity and in most cases two to three times this value. The manufacturers should test each line of their breakers or make periodic tests of breakers as they are brought through the factory which would cover this rating, these currents should be of relatively low voltages, thereby requiring a small generating capacity. These tests should also include the current-carrying capacity of the auxiliary contacts for the duration of time they would be required to carry the heavy current after the parting of the main contacts.

Rated Interrupting Capacity

The limiting factors entering into the operation of an oil circuit breaker when interrupting a current have never been conclusively determined. The present-day practise of rating oil circuit breakers to interrupt a given r. m. s. current at normal voltage two times at a two-minute interval and then be in a condition to be closed and carry its rated current until it is practicable to inspect and make necessary adjustments, is not in accord with operating requirements as reported in the replies to the questionnaire. There is considerable difference in the operating requirements depending upon the character of the system. On such parts of a system as will not cause interruptions to service by the opening of an oil circuit breaker, it is general practise not to throw in the breaker again until the circuit is tested and in some cases until the breaker is carefully inspected as well. In other cases where the opening of an oil circuit breaker interrupts service such as distribution feeders, single transmission lines, etc., there is a general tendency to throw in the breaker as soon as possible without testing the circuit. In many cases, the latter method restores service, as the opening of the oil circuit breaker may have been caused by a flash-over or other intermittent trouble. In some of these cases the operators find that even after the breaker has opened automatically, two, three, four and some as high as five times, a reclosing of the breaker will restore service, and, therefore, they feel it desirable to have the breaker rated to withstand this service.

Considerable time is required in testing a feeder, and in many cases the only available means is by closing the circuit through the oil circuit breaker. In some cases, however, this heavy requirement on the oil circuit breaker could be relieved by the installation of proper testing facilities, particularly where there are many feeders or points of high power supply.

It is felt that the interrupting capacity tests that are being made at the present time in the factories and on some of the larger companies' systems will give a better idea of the limitations of the oil circuit breaker to withstand the stresses produced by the reclosing feature. Also the installation of recording devices on systems which will give some record of the service imposed on a breaker under short-circuit conditions should lead to progress in the design of oil circuit breakers.

Some companies consider it desirable to compare the constants of the circuit breaker, such as tank dimensions, length of break, speed of operation expansion chamber etc., before selecting one for their conditions, and it is hoped that the results of the above tests will tell us more regarding the relative importance of these features.

It is felt that the manufacturer should, as soon as possible, give a rating on oil circuit breakers on the single-shot basis and proportion these ratings on the reclosing basis. By single-shot basis is meant interrupting of the current, as defined in the next paragraph, and the switch being capable of reclosing and carrying full-load current. As an example, a breaker rated at a certain value on the single-shot basis would be rated at a somewhat lower value on a two-shot basis, and other values below this on a three-shot, four-shot, etc., basis.

There is considerable difference of opinion as to what should be considered as satisfactory operation of an oil circuit breaker. The opinions vary so much that we hesitate to recommend a definition and would therefore suggest that the satisfactory operation would mean the rupturing of current within a definite time limit after the energizing of the trip coil, which time allowance could be relied upon for selective operation of relays on the system, without throwing burning oil outside of the tank or causing permanent deformation of tanks or any of the current-carrying parts.

It is suggested that the rating be made with only the manufacturer's factor of safety to cover any inequalities of materials and manufacturing processes so the purchaser of an oil circuit breaker could then rely on a given rating at all times and should not count on more.

Very few data were given which would show the relation of the constants (reactance and resistance) of the circuit as affecting the interrupting capacity of the breaker, although some tests made by one of of the operating companies showed that reactance imposed a heavier duty on the oil circuit breaker than resistance for the same value of current.

In several cases reported, the increase in the speed of operation of some of the older type breakers has made an improvement in the interrupting capacity.

Ninety per cent of the cases reported have found venting the tanks desirable.

There is no universal standard for oil to be used in circuit breakers, although some companies have interchangeably used oil of one manufacture in breakers of another. It would be desirable if some standards could be adopted by the oil circuit breaker manufacturers so as to reduce the number of types of oil required for stock with companies having several makes of breakers.

CORRESPONDENCE

INPUT RESISTANCE OF THERMIONIC TUBE

To the Editor:

In the January issue of the JOURNAL, there appeared an article by F. C. Blake entitled "On Electrostatic Transformers and Coupling Coefficients." On page 28 of this article occurs the following sentence: "Van der Pol's experiments seem to call in question the statement made by Miller that the input resistance of a thermionic tube is always positive for a capacity load, for Van der Pol with such a load actually had the tube working as an oscillation generator." In a footnote, Mr. Blake refers to my Scientific Paper No. 351 of the Bureau of Standards.

In view of the facts that the statement which occurs in my paper is of considerable fundamental importance in vacuum tube theory, that it is based upon mathematical theory which has been checked by a number of others and that I have also checked my theoretical results very carefully by measurements, many of which are described in my paper; it does not seem advisable to pass over a casual questioning of the validity of my results.

I have examined Dr. Van der Pol's paper in *Phil. Mag.* 38, p. 90, 1919, and do not find anything other than results which support my conclusions rather than render them questionable. In the experiments outlined therein, the plate circuit of the tube contained a circular wire 60 cm. in length in series with a condenser having plates 10 cm. in diameter, the capacity of which could be varied by varying the distance between the plates. With the plates separated a few centimeters oscillations were not obtained, but when the distance was reduced to about one centimeter, oscillations were set up. The load in the plate circuit of the tube, therefore, consisted of an inductive reactance and capacity reactance in series and as should be the case, a reduction in the capacity resistance led to the generation of oscillations. In the oscillating condition and assuming coupling only through the tube capacities, the load in the plate circuit must have been inductive. This can be checked by a rough calculation using the data given by Van der Pol. The capacity of the condenser with a plate separation of one cm. was about 10 micro micro-farads, the circular wire, if of No. 16 gage or smaller, would have an inductance of 0.6 microhenry or more. The wave length of the oscillations was 3.75 meters corresponding to a frequency of 80 million. Under these conditions the inductive reactance was +300 ohms, the capacity reactance −200 ohms and hence the net load was inductive.

The above facts do not substantiate the question raised by Mr. Blake as to the validity of my results.

JOHN M. MILLER

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Bureau of Standards

Permissible Operating Temperatures of Impregnated Paper Insulation in Which The Dielectric Stress is Low

BY D. W. ROPER

Superintendent of Street Department, Commonwealth Edison Co., Chicago

FOR a number of years the standard low-tension direct-current feeder cable in Chicago was 1,000,000-cir. mil two-conductor concentric paper-insulated cable with three pressure wires laid up with the outer conductor. Apparently there has been the greatest tendency to overload this particular size of cable more than any other as, with both single and concentric cables in service, it was difficult to make a proper distinction between the carrying capacity of the two kinds of cables. About ten years ago we had two cases in which the cables of this kind were called upon to carry loads somewhat larger than had been customary, and steadily throughout the day instead of a short peak in the evening. The two customers in these cases, in different portions of the city, were both manufacturing customers with an eight-hour load, and on account of some increase in business they increased their load on short notice when no cable was available for another feeder to their premises. In each case, the cable has to be ordered from the factory so that this unusual load was carried by these cables for some three or four months. In the first case of this kind we were so disturbed about the temperature that we made a rather extended series of temperature measurements, using one of the pressure wires imbedded in the outer conductor as a resistance, and determining the temperature by the rise in resistance. This, of course, would give us the temperature of the outer conductor which would be probably 8 or 10 deg. lower than the inner conductor. The temperature measured in this manner was slightly above 100 deg. cent., and as there was some doubt regarding the accuracy of the determination made in this manner, it was checked by cutting a small hole in the lead sheath of the cable and in the outer insulation, and measuring the temperature of the outer copper with a thermometer. The temperature taken in this way checked very closely with the temperature as determined by the rise in resistance of one of the pressure wires. The insulation removed in this manner was carefully preserved and compared with the insulation in a piece of new cable, and it was impossible, by careful examination, to discover any appreciable difference.

In the second case which occurred some months later, we were not so disturbed about the damage to the insulation, although the load carried per cable was approximately 10 per cent heavier than in the first case. The temperature measurements were on this account omitted. The line was carefully patrolled several times per week, however, in order to detect any symptoms of impending trouble and a number of minor mechanical defects in the lead sheath were discovered during the time that this cable was overloaded.

In each of the above mentioned cases the service over these cables was discontinued, a few years after the period of overload, due to the customers moving to another location. The cables were, therefore, removed, carefully examined, the insulation found to be in good condition and the cables reinstalled at another location.

Messrs. Clark & Shanklin in their paper on "High-Tension Single-Conductor Cable," presented before the Institute on June 24th, 1919[1], give some data for the radiation constants of conduits under average heating and hot-spot conditions. The authors of the paper advise that the figures for average heating were determined as the result of a large number of observations, and the carrying capacity obtained from these data appears to check fairly well with our experience with the sizes of cables under discussion. In later years 1,000,000 and the 1,500,000-cir. mil single-conductor cables have been our standard sizes for low-tension direct-current feeders. The carrying capacities of these several sizes of cable as determined from the Clark and Shanklin data for average conduit conditions and for a maximum copper temperature of 100 deg. cent. are as follows:

Size	Load per conductor Amperes
1,000,000-cir. mil single conductor	1110
1,500,000-cir. mil single conductor	1360
1,000,000-cir. mil concentric	790*

*Note: this figure is one-half the current for a 2,000,000-cir. mil single-conductor cable.

Our records indicate that a considerable percentage of all of our low-tension feeder cables will exceed these figures for a few hours each night during a month or two of the maximum load period in the winter.

The paper by R. W. Atkinson in the September, 1920 JOURNAL of the Institute gives the data for calculating temperatures of copper conductors in cables by an entirely different method. For the purpose of calculating the maximum temperature by the Atkinson method, the air temperature in an idle duct in the conduit in which the cables are installed and the load carried by the cable are necessary. During the past few months we have made a number of temperature surveys and have calculated maximum copper temper-

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1. Vol. XXXVIII, p. 944.

atures by the Atkinson method, and have made curves of temperature over a number of consecutive days in some of our heavily loaded conduits. These curves show that the minimum temperature occurs Monday morning after the light loads on Saturday afternoon and Sunday, and further that there is a gradual increase in the maximum daily temperature from Monday until Friday. It is, therefore, a rather tedious job to discover from such tests and from our load records the total length of time during any given period that the copper temperature has exceeded any specified figure on any particular cable. The results obtained to date by this method indicate the maximum copper temperature of our low-tension feeder cables in the large and crowded conduits immediately adjacent to the substations is generally higher than 105 deg. cent., and in a number of locations considerably exceeds this figure for several hours per day for each of five days in the week during the winter months.

In one or two cases where, in the case of our older substations, we have 20 or 24-duct conduits leaving the substations with nearly all ducts occupied with loaded feeder cables, vacant duct temperatures of approximately 100 deg. cent., are found for a short time on Friday afternoon during two or three weeks in December. Such idle duct temperatures, together with the load readings, indicate by the Atkinson method a maximum temperature approaching 200 deg. cent. on the inner conductor of a concentric cable. One of the concentric cables in this conduit was removed and examined for the purpose of this investigation, and incidentally an opportunity was afforded to report on one item not scheduled. Upon removing this section of cable, a hole about one inch in diameter was found in the lead sheath about eight inches from the mouth of the duct. It had apparently been caused by the sheath catching on the edge of the duct when the cable was installed without being noticed by the workmen. In the immediate vicinity of this hole, the paper insulation is not only quite black but also quite brittle, so that it breaks very readily when handled. At another point thirty feet away, the paper insulation, while slightly darkened, is still well filled with compound, and pliable, although it has lost some of its strength. From the information secured from this sample of cable and from other samples secured from similar crowded conduits in the vicinity of large substations, I think that we may reasonably conclude that when the copper of one of the low-tension cables on our distribution system reaches a maximum temperature of 180 deg. it is being heated beyond a safe limit, and deterioration of the insulation will result; and further, that the deterioration will be greater if there are holes in the lead sheath at the point where such temperatures are reached.

During the past year in connection with changes on our distribution system, we have removed concentric cables from locations where records and subsequent examination into the conditions indicate that the maximum copper temperature must have materially exceeded 100 deg. cent., but the exact amount cannot be definitely stated. We do know, however, that in such cases the insulation has been found in good condition, so that the cables have been reinstalled and placed in service at a different location.

The time during which the maximum temperature is maintained has undoubtedly a considerable bearing on the subject. We know, for example, that the insulation next to the lead sheath of a new cable shows no sign whatever of damage by heating, although the lead is applied at a temperature which probably exceeds 300 deg. cent. We know, also, that when our cables are suddenly overheated because of a burn-out at a more remote point from the source of supply, that the insulation shows no indication whatever of damage, although the temperature of the copper must have considerably exceeded 100 deg. cent. for a short period. It is apparent, therefore, that not only due consideration should be given to the time during which the maximum temperature of the copper persists, but also that in an operating system it is not possible to determine the maximum safe limit exactly, as the temperatures are continually changing and it is not possible under working conditions to maintain any particular maximum temperature for any considerable time. Apparently the best that can be done is to determine the maximum temperature and also average curves showing the number of hours per year that temperatures near the maximum are maintained. From an examination of the insulation of cables corresponding to a number of such curves we should be able to establish, first: A lower limit at which the insulation will not be injured, even when the temperature is maintained for long periods of time; and second: An upper limit above which we know that the insulation will be injured if such temperature is maintained for any considerable time. From the information so far obtained in Chicago, the best that can be done is to place the lower limit at about 110 deg. cent. and the upper limit at about 180 deg. cent. It is recognized that these limits may be too widely separated to be of material value in the settlement of the question at issue, but it is hoped that as further investigations are made, additional information will be forthcoming which will serve to bring these limits within a narrower range.

The Story of the Induction Motor

BY B. G. LAMME

Chief Engineer, Westinghouse Electric & Mfg. Co.

This paper covers the history of the technical side of the development of the induction motor, principally as the author saw it. It indicates the various stages of development from the early Tesla motor, with polar field construction, to the distributed field construction, and from the early wound-rotor type to the later almost universal cage type. Reference is made to the development of the cage motor with high starting torque, and the reasons which led up to it. The early single-phase induction motor is also treated, indicating various stages in its development.

The latter part of the paper covers the growth of the motor as an industrial apparatus and its application to various unusual services, such as heavy mill work, locomotive operation, ship propulsion, etc. Speed control of such motors is also described.

The papers refers, principally, to American practise, although occasional reference is made to foreign work. The description covers, primarily, the development work of the company with which the writer is connected, and reference to the work of other companies is incidental, due, largely, to lack of sufficient inside data.

LOOKING back over the technical history of the induction motor, we see an apparatus which is of extreme theoretical interest, and, at the same time, is of inestimable practical value. It is impossible to define just what effect it has had upon the general development of the electrical industry. It is probably safe to say that without this motor the whole trend of the art would have been greatly modified; for unquestionably the induction motor has had a very great part in placing the polyphase alternating current system in its dominating position of today. Practically 95 per cent of the generated electric power of today is by alternating current. It is beyond belief that the a-c. system could have reached anything like this dominating position if there had been no induction motor for the utilization of alternating current for power purposes. The induction motor should, therefore, be considered as a fundamental element in the alternating current system as a whole.

Considering the importance of the induction motor, the writer has considered it to be of interest and value to record a history of its development as given in the following pages. It should be understood distinctly that this applies only to American development, and only insofar as has come within the writer's knowledge and experience. European countries, it should be understood, were not behind America in the development of the motor itself, and, in fact, in some ways Europe was a year or two ahead. The historical Lauffen-Frankfort experiment of 1891, where a relatively large induction motor was operated over a long transmission line, is a good example. The story of the European development would be a most interesting account in itself and, unless this is soon recorded, undoubtedly valuable parts of the early history of this work will be lost.

This story, as presented, covers principally those developments with which the writer has been in more or less personal contact through his connection with one of the large manufacturing organizations. If members of other organizations would record their part of the story, it would undoubtedly be of material benefit to future engineers. All manufacturers have had their troubles and their successes and their triumphs and discouragements, presumably pretty much as shown in this story. It is one of the greatest misfortunes of the engineering profession that so few of the great pioneers and the development engineers have recorded the steps which have led to success or failure. With such a record, a failure may be of just as much value as a success, for the art is built upon failures as well as successes.

The induction motor, in its early days known as the "Tesla motor", appeared in 1888. It is difficult to say just when it was invented. Tesla invented it without question. Professor Ferraris also invented it. Shallenberger was treading on its heels in his alternating-current motor-driven meter. Bradley was very close to it in his polyphase synchronous converter. Thomson was also close to it in his three-coil arc machine. All of these men were working independently of each other, so that it appears that the induction motor was bound to be invented sooner or later. However, to Tesla belongs the true credit of independent invention and of bringing the matter before the public in such a way as to lead eventually to practical results.

When the Tesla motor first came out, it was doubtful whether anyone had any real conception of its actions or its characteristics as we now see them. Tesla knew two things, namely that if a magnet was moved across a conducting surface or plate, it would tend to drag the plate with it, and that the action of such a moving magnet could be produced by out-of-phase alternating currents. These are very elementary conceptions, but, come to think of it, what more fundamental conception of the real operation of the induction motor can there be, than the above? The induction motor of today is simply the above action put in practical form. True, it is an immense jump from these early conceptions to the practical machine of today. The intermediate gap has required years and years of highest effort to span, and unquestionably some of the best analytical ability expended in the electrical field, has been on the induction motor problem The development of the induction motor being, in reality an analytical problem, it did not make much

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headway in the "cut and try" days of 1888 and '89, when the Westinghouse Company was undertaking to put it into commercial form. Our only frequencies in those days were 133 and 125 cycles and the only alternating current supply circuits were single phase. None of these were suitable for the new motor and, therefore, it was badly handicapped at the start. In

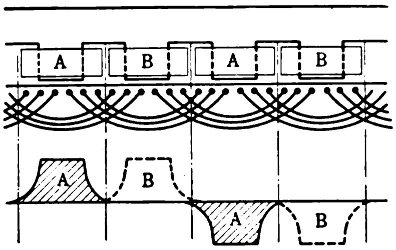

Fig. 1

fact, it was an almost hopeless proposition to bring it out commercially. However, the full extent of the handicap was not fully realized at the time and, therefore, a vast amount of development work was carried on with the idea of producing an operative device. Tesla worked on this development himself in 1888 and '89 assisted by Mr. C. F. Scott who later took charge of the development and made very important advances. Considering the lack of knowledge of magnetic problems and conditions of those days, it is really a source of surprise that Mr. Scott developed the motor as far as he did. He devloped the slotted secondary, with overlapping distributed winding, up to a quite effective point. Apparently he did not fully recognize the relations of secondary resistance to starting torque, nor did he know the inherent speed-torque characteristics of the machine, but neither did any one

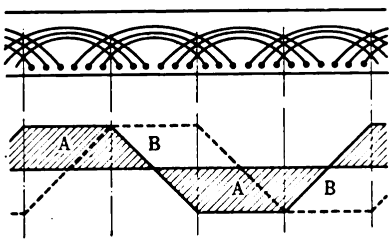

Fig. 2

else. In fact, a full working knowledge of the characteristics of the induction motor did not develop until some years later. However, Mr. Scott's work showed quite clearly that the motor required some materially lower frequency than any in existence at that time, but as such lower frequency and polyphase circuits were not yet in existence he was fighting a hopeless battle for the motor

These early Tesla motors, as developed by Mr. Scott, showed quite good operating characteristics and might have proved commercial with suitable supply circuits. In fact, some small installations for operating mining machines were made near Pittsburgh, which were successful from the motor standpoint. Yet the motors were fundamentally handicapped in one feature, namely, the primary flux distribution. In those days, distributed field or primary windings were unknown and only the simple polar types of magnetic construction were recognized. In consequence, these early induction motors were made with distinct polar projections, each projection carrying a primary or field winding, with alternate coils belonging to one phase of a two-phase circuit. The flux, therefore, of the adjacent poles or phases did not overlap each other as in the modern induction motor and uniform progression of the magnetic field, as we now understand it, was not possible. This early arrangement might be illustrated by Fig. 1. Obviously with such an arrangement, the magnetic field of one pole covered a relatively small percentage of the pole pitch, and one of the greatest steps forward, in motor design, was the recognition of the advantages of distributed overlapping primary windings. The difference may be illustrated by Fig. 2. Here it may

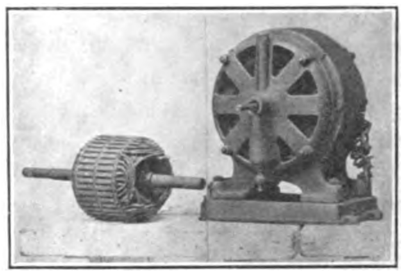

Fig. 3

be seen that the magnetic flux per pole covers practically the whole pole pitch as compared with one-third of the pitch in Fig. 1. Moreover the magnetic field can progress at a comparatively uniform rate and the resultant of two phases can give a magnetic field comparable with either one of the phases. Fundamentally, the more important feature in the distributed field winding is the large magnetic flux per pole compared with the former construction. This has a direct bearing upon the output characteristics of the machine. With the same expenditure in magnetizing current, an increase to two to three times the total flux means a revolutionary improvement in the characteristics of the machine in general.

When Mr. Scott dropped the work in 1890, primarily due to the handicap of unsuitable supply system, as mentioned before, but also due to financial stresses in the company's affairs, he had probably gotten out of the motor about all that was possible with the type and construction and knowledge at hand. As stated before, he had a distributed short circuited secondary winding adapted for averaging the torque conditions, although not of a type desirable for later machines; he had an odd or hunting tooth in the secondary to

lessen magnetic locking; he also tried the skewed secondary construction; he had a relatively small air gap; and he had a well laminated primary structure. In general appearance, the motor was not unlike some of the induction motors of today, see Fig. 3. This was a prideworthy result, considering that it was developed largely by "cut and try" methods.

In 1890, this induction motor development as a whole, was dropped by the Westinghouse company and was not taken up again actively for about two years, although some slight experimental work was carried on meanwhile.

During 1890 and '91, slotted type armatures for railway motors and direct-current generators were developed by the Westinghouse company to supersede the older surface-wound types. In carrying out this work, the writer considered the use of similar types of windings for alternating-current machinery and even built a slotted type single-phase alternator armature, as early as 1891, this having a large number of slots per pole. These developments led to the consideration of the use of a direct-current type of slotted armature winding for generation of *polyphase* alternating current and it was recognized that the mere addition of polyphase collector rings to the armature winding of a direct current machine would allow it to be operated as a polyphase alternator. This was principally in connection with the possibilities of building synchronous converters. This work also led to the consideration of similar types of windings on induction motors. This led the writer to take up the induction motor problem, in his idle moments, and in working out the idea of a distributed polyphase winding of the above type, he realized that the magnetic conditions set up by such a winding would be far superior to those of the early Tesla motors. He explained this matter to Mr. C. F. Scott, who was very much interested, and it was then suggested that the writer take up this work, at the first opportunity, with a view to building such a motor. Mr. Albert Schmid, then superintendent of the company, was also so much interested that he soon authorized building such a motor experimentally This was undertaken about 1891. The induction motor situation looked more promising at that time, for in 1890, it had been decided, after careful consideration, that a new standard frequency, much lower than 133 cycles, should be adopted by the Westinghouse company. Mr. L. B. Stillwell, who was giving this matter active attention, finally, after considering all sides of the question, recommended in favor of 60 cycles, and, in 1891, this was making some progress. This, therefore, indicated that one handicap on the induction motor would soon be removed. It is true that polyphase circuits had not yet come, but we were hopeful in those days that this would be one of the next advances.

This first motor with distributed windings, was tested in 1892. This motor had both distributed primary and secondary windings, with a number of secondary slots prime to the field slots. The secondary winding was of a polyphase type, short-circuited on itself at the polyphase terminals. The stator was the primary and the rotor was the secondary. In fact, this motor resembled very much the modern induction motor.

On test, this motor gave very surprising results, compared with anything which had gone before. Its pull-out torque was very large and its starting torque was very much better than expected. In fact, we felt that we had here practically a commercial motor. The interesting feature was that the current capacity of this motor was materially larger than anticipated, probably due to the effect of the distributed winding in dissipating the heat. Taken all in all, this motor was most satisfactory in showing that very good induction motors could be built when the proper time came.

An interesting test in connection with this motor was in determining the effect of short-circuiting the secondary winding from coil to coil, instead of the usual polyphase terminals. In the final test, the insulation was scraped or burned off the end windings of the secondary, exposing the bare copper, and the ends were then thoroughly soldered together, thus making a continuous ring of metal at each end. In other words, this was practically a modern type of cage winding. On test, this showed even better results than before and proved conclusively that short-circuiting of all the end windings together was, if anything, much better than simply short circuiting the groups of windings on each other. In other words, this was an early proof that the cage type secondary was a most effective type where the starting conditions would permit. However, the cage type secondary had been tried in Europe at a still earlier date.

For a year or so, the induction motor development lagged due principally to the fact that there were yet no supply systems. In the latter part of 1892, however, the Westinghouse company prepared designs for a large induction motor to be used in connection with the World's Fair exhibit at Chicago in the following year. This motor was actually built and put on exhibition and a description may be of interest as it was apparently the first quite large induction motor put in operation in this country.

The World's Fair lighting system, as laid out and installed, was 60 cycles, single phase, 2200 volt. However, in the early stages of the development of the lighting machinery, Mr. Westinghouse suggested that this would be a good opportunity to illustrate the possibilities of the polyphase system, and, therefore, he proposed that the generating units, of 1000 h. p. each, be made with double fields and armatures, that is with two 500 h. p. machines side by side on the same shaft, but with the single-phase armature windings of the two units displaced 90 deg. from each other. His idea was that the general lighting of the exposition would be from single-phase circuits, as was the usual

practise in those days, but by bringing two out-of-phase circuits to the same locality, polyphase current would be available for operating polyphase apparatus. This arrangement was adopted and, therefore, this Chicago exposition represented the first large installation of polyphase generating machinery in this country.

On account of the availability of polyphase current, a special polyphase exhibit was then devised for the Electricity Building at the Fair. In this exhibit was a 300-h. p., two-phase 220-volt induction motor, to be operated from the polyphase lighting circuits. This motor in turn was belted to a 500-h. p. a-c.-d-c., 30-*cycle*, generator for delivering 550 volts direct current and approximately 390 volts, two-phase, from its collector rings. The low-frequency current from the a-c. side of this a-c. - d-c. generator was then carried, through step-up and step-down transformers, to the collector rings of a machine of corresponding size, used as a synchronous converter, to deliver direct current at about 550 volts. This synchronous converter was started by means of an auto-transformer on the a-c. side, with five voltage steps. In addition, a synchronous converter of about 50 to 60 h. p., giving about 60 volts d-c., was also operated. It can thus be seen that this was a true polyphase exhibit and it was very much ahead of its time, as neither induction motors nor synchronous converters were yet on the market. Moreover, the 300-h. p. induction motor was apparently far ahead of anything yet built, in regard to capacity. This motor had a rotating primary with stationary secondary. It had twelve poles and the distributed primary winding was of cable threaded through partially closed slots, this construction being adopted in order to decrease the primary magnetizing current, thus indicating that even at that early day this feature was quite fully appreciated. The stationary secondary also had partially closed slots with one conductor per slot, these conductors being connected to give two secondary circuit 90 deg. apart. When the motor reached full speed the secondary circuits were short-circuited, but during starting they were closed through a series of long heavy carbon rods, placed in a basement beneath the exhibit, these rods being used for starting resistance. Not much was known about starting resistances in those days, and, as this carbon starting outfit would sometimes get red hot while the motor was being brought up to speed, it was not considered desirable to let the public see it. However, the arrangement was quite effective and, although crude, nobody knew anything better. This exhibit was started about the first of July, 1893, being late in delivery due to the many new features involved. When this exhibit was first started it created quite a commotion, as many of the neighboring exhibitors had concluded that the apparatus was never intended to run. It made enough noise to attract an undue share of attention and, therefore, was quite successful as an exhibit. The writer was present during the starting and the first few days of operation of this exhibit and noted many amusing incidents. For instance, one morning he observed a very intelligent looking man staring quite intently at the large induction motor. Upon being asked if he wanted to know something about it, the man said that he wanted to know what kind of a machine that was. Upon being told that it was an induction motor of 300 h. p. capacity, he blurted—"My Lord! I didn't know they made them that big." He then explained that he was a college professor from a southern university, and was quite interested in induction motors, but thought that they were built mainly on paper and didn't know that induction motors had been made which would run and carry loads. This is an instance of the kind of attention the apparatus attracted.

Something should be said here concerning other polyphase exhibits at the Chicago Fair. The A. E. G., of Berlin, had an exhibit right across an aisle from the Westinghouse. . This exhibit while much smaller and less pretentious than the Westinghouse, was quite interesting as it contained a small polyphase generator, of about 100 kw. capacity, and an induction motor of about 75 h. p. This exhibit was in the charge of a young engineer who was apparently concerned simply with technical matters, while the daily operation was in the charge of an older man. A few minutes after the writer first called at the Westinghouse exhibit, he was informed of the A. E. G. exhibit across the aisle and immediately visited it. Upon examining the A. E. G. generator and noting its *distributed* armature winding, he asked the young engineer who was present, how the regulating characteristics of the distributed armature winding compared with those of the toothed type. The German engineer looked at him and replied—"Ah, you are from the Westinghouse company", and he volunteered nothing further. An interesting thing about this A. E. G. induction motor was the use of a water rheostat in the secondary, for starting purposes. One evening when the jury on electrical awards visited the A. E. G. exhibit for inspection and report, the motor was started and a fire resulted in the starting apparatus, which created excitement and brought the fire engines. It was found that the water rheostat had caught fire, which fact in itself was considered quite a joke among the Westinghouse engineers. This A. E. G. exhibit was interesting in showing that Europeans and Americans were independently developing polyphase apparatus along very similar lines.

In the Schuckert exhibit, also in the Electricity Building, there was a polyphase induction motor of small capacity with distributed windings. This, however, was not operated as there was no suitable supply circuit.

If the writer remembers rightly, the General Electric Company also had certain polyphase apparatus on exhibition. A synchronous converter of about 75

h. p. capacity was shown. However, no polyphase apparatus in operation was observed.

It was in 1893 that the induction motor business in this country really got into motion. It was about this time that the question was taken up, in a conference in the Westinghouse company, as to how to get this motor on the market. After various plans had been discussed, the suggestion was advanced by the writer

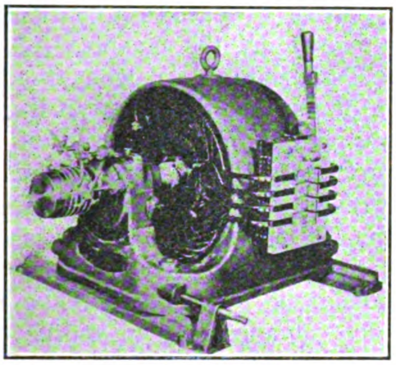

FIG. 4

that if we would make a "fad" of polyphase generators, so that everybody would buy them, the motor question would soon settle itself. This suggestion apparently was considered a good one, for instructions were given immediately to get out a standard line of polyphase generators and push them on any and every occasion. This was done and it was remarkable how quickly the public actually took to the polyphase generator. It became a real fad and soon developed into standard practise. The development of a standard line of induction motors

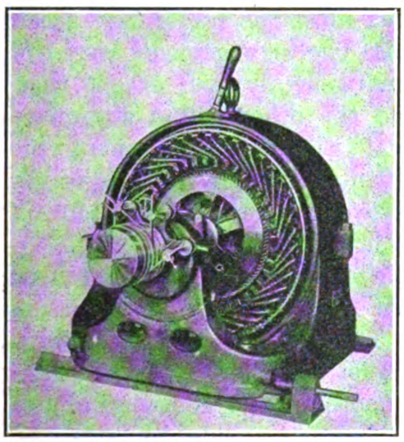

FIG. 5

was also authorized, and, to illustrate how quickly the commercial demand came, it may be said that customers' orders were taken for the motor quite a long time before any of them were ready for the market. In consequence, we had to rush the first line of motors on the market, even before we had much chance to do any development or experimental work. In fact, most of the experimental data had to be obtained from motors on customers' orders. However, this was common practise on most machinery in those days, and we got our data piecemeal, from several orders, rather than from complete tests on any one piece of apparatus. This first line of motors was for 60 cycles. Work was started on it sometime in 1893, and in 1894 motors were being completed for the market.

These first Westinghouse commercial motors, were of the rotating primary type with stationary secondaries. This construction was largely because the secondaries of these early motors were made with a number of comparatively large bar conductors with correspondingly low voltage and heavy current. As starting resistance was used, this meant that the problem of handling the current by collector rings and brushes was a quite serious one, and, therefore, by placing the secondary winding on the stationary element and the primary on the rotor, the collector ring and brush problems were much simplified. The primary winding was always of considerably higher voltage, with comparatively small currents which thus could be handled much more easily.

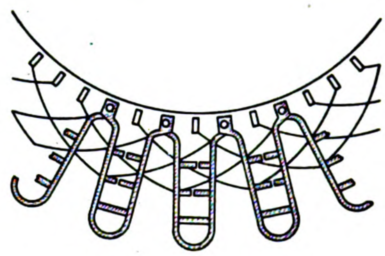

FIG. 6

On these first motors, "closed-coil" two-circuit types of secondary windings were used, with four leads carried out to a pair of switches on the frame of the machine. A cast iron resistance grid was connected permanently across each phase and the switches simply short circuited these grids after speed was attained. This was a relatively crude arrangement, but simplified the problem of putting these early motors on the market. We would make these iron grids with "bridges" in them and on test we would simply saw out bridges until we got the desired starting characteristics.

On one of these early motors the writer made some tests to determine whether two-phase short-circuiting of the secondary winding gave as effective results as three-phase. He brought out leads from the stationary winding to make a number of combinations and he made a very interesting discovery. It was found that when the closed coil winding was short-circuited at three points, representing three-phase, a certain pull-out torque was developed. Short circuiting at four points, representing the socalled two-phase, but in reality four-phase, a higher pull-out torque was developed. Short circuiting at six points, a still higher torque was developed and at eight points,

etc., up to twelve, there was improvement. Beyond twelve points short-circuited there appeared to be but little gain. Furthermore, it was noted that the operating characteristics of the motor as a whole were considerably improved with more short circuits. This further verified earlier conclusions that from the running standpoint a complete cage winding was the most effective type. This then led to the development of an improved secondary winding which combined resistance starting with the effects of a cage winding at full speed. A closed-coil, two-circuit or "series" type of winding, of low voltage, was used in the secondary, with a large number of iron grids connected *between adjacent coils*, sufficient in number to span, all told, practically one pole pitch of the secondary winding, see Fig. 6. This gave very effective starting conditions. As full speed was attained, a short circuiting ring, surrounding the secondary winding, was shifted circumferentially to bring it into contact with the secondary bar end connectors at a large number of points, thus changing the winding virtually to a cage type,

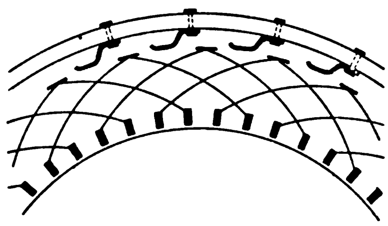

FIG. 7

Fig. 7. Thus the advantages of resistance starting and cage running were obtained. This was designated as the type B motor to distinguish it from the earlier motors gotten out by the Westinghouse company. The above construction was quite effective and motors of this type gotten out at this time and during the next year or so, are still in operation. This motor was so successful that a number of Westinghouse people said it was no use trying to beat it, as it was too near perfection. However, it was unduly expensive in construction and had certain inherent limitations which promised eventually to be troublesome. The rotating primary was all right for 200 and 400 volts, but for materially higher voltages, which showed promise of coming, it did not look so well. Also at this time, motors of one h. p. and smaller were being built with stationary primaries and with rotating cage type secondaries, and these indicated possibilities which were well worth following up.

It should be stated also that about the same time that the Westinghouse polyphase development opened up, a corresponding development took place in the General Electric Company and it began to put out polyphase motors with distributed primaries. Apparently this development was entirely independent of the Westinghouse company and arose primarily from analysis of the true conditions required for a successful induction motor. However, on account of the patent situation, the General Electric Company soon brought out what was called the "monocyclic system", with a view to avoiding the Tesla patents This was really a form of unbalanced polyphase system, in that it had one main phase and one auxiliary or "teaser" circuit for furnishing, principally, magnetizing current to the motor. The energy supplied to the motor was largely single-phase, but the magnetization was polyphase, at least to a considerable extent. This was supposed, by the inventors of the system, to avoid the Tesla patent, but when one looks at the problem from the present viewpoint, it is quite evident that this was simply a special case of the general polyphase problem. The General Electric Company developed excellent motors to operate with this monocyclic system. In fact, it was almost a case of necessity to use good motors with such a system, and, therefore, the monocyclic system may have been partly responsible for advancement in motor designs and construction. A motor which would work well on the monocyclic system would work extra well on a balanced system. One of the leading types of motors gotten out by the General Electric Company, either in this period, or at least quite early, was one of a rotating secondary type, with low resistance secondary windings, with iron or alloy grid resistance inside the rotor connected permanently to the windings, and with a mechanical means for short circuiting such resistance after the motor had accelerated to a certain point. In the Westinghouse type B motor, as already described, grid resistances were permanently connected to the low resistance secondary winding with provision for mechanically short-circuiting the windings at a number of points after the motor had accelerated. Obviously, these two arrangements were very similar in principle and general type, except that one had a rotating and the other had a stationary secondary. The General Electric arrangement presented one distinct advantage in having a stationary primary, which has proved to be the preferred form for induction motor work in general.

The Stanley-Kelly Company also put on the market an induction motor which, it was assumed, did not infringe the Tesla patents, because it did not produce a rotating magnetic field in the usual sense. The primary in this motor, really consisted of two polar type single-phase primaries side by side, but with the two sets of poles displaced 90 deg., and excited by currents 90 deg. out of phase with each other. These two single-phase fields acted upon a common secondary core and winding. The pole tips were slotted and contained a special distributed type of damper winding for lessening the armature reactance.

Due to the fact that the two magnetic fields set up were assumed to be simply alternating in space and not rotating, it was believed that this Stanley-Kelly motor, therefore, did not possess the rotating field of

the Tesla motor, and thus avoided the patent. However, the chances are that any modern designer who would analyze this machine, would say at once that it was simply a special form of the Tesla motor and obeyed the general laws of such apparatus. These motors were put out in considerable quantities, during the 90's, and were built very largely for two-phase, as the structure was better adapted for this. If the writer remembers rightly, the Stanley-Kelly Company also put out some split phase motors, using condensers and reactances to get the desired phase relations. These attracted considerable attention at first, but eventually they dropped out of sight, as was the case with practically all induction motors using condensers for phase splitting. Apparently the inherent difficulties in the early condensers themselves were an undue handicap. Practically all companies which built induction motors tried, at some time, the condenser method of phase splitt ng. The General Electric Company tried this scheme on a relatively large scale. The Westinghouse Company tried the scheme experimentally to a considerable extent, but put out very few motors, principally because it did not have a sufficiently good condenser.

By 1895, the polyphase motor had become pretty firmly established as a commerical device and was making great progress. Except in very small sizes, resistance starting was used exclusively. The cage type secondary was well known, but was used only in connection with small motors or for small starting torque, as it was considered that this type of machine inherently had insufficient starting torque for heavy motor service. This notion was overthrown through a radical development which will be described later.

While the polyphase motor was being developed, the single-phase induction motor was also given much consideration. In fact, in the very early Tesla work, in 1888 and '89 when single-phase circuits of 133 cycles and 125 cycles were the only ones available, various attempts were made to construct single-phase motors, operated through phase-splitting devices. This was usually on a basis of two-phase circuits on the motors themselves with unequal reatcance in the two circuits. However, this did not prove successful even for fan motors.

It was discovered, quite early in the game, that the two-phase induction motor of the early Tesla type would operate quite well on single-phase by opening one phase after the motor was up to speed. It was also discovered that if the motor was at standstill it could be started up in either direction by giving it a little push at the pulley. Moreover, it was noted that with the secondary set in certain positions with respect to the primary, the motor would start itself, with current thrown on one primary phase only. It is thus evident that certain phenomena of the single-phase induction motor were recognized as early as 1888 and '89.

From 1890 to '94, the Westinghouse company built for commercial purposes, a number of single-phase synchronous motors which were used in connection with certain western mining power work. These single-phase synchronous motors were not capable of starting themselves and, therefore, the practise, was adopted of starting them by means of induction motors. The writer acquired considerable experience in this work and succeeded in making some fairly effective split-phase motors for starting the synchronous type machines. In one instance, he took an early experimental motor and placed a distributed primary winding on the stator element and used a high resistance bar winding on the rotor, this bar winding being tied together at the ends by *heavy high-resistance alloy rings.* In the first trials, the motor started and accelerated the load all right, thus proving that satisfactory torque conditions were obtainable, but as the secondary bars were soldered in slots in the end rings the solder all melted and came out. A metal wedge arrangement was then adopted, instead of solder, with a view to obtaining good joints by mechanical means. It was soon found, however, that unequal expansion of the secondary bars, in the early period of acceleration, was sufficient to cause relative movement between the bars and the end rings at the wedged joints. Eventually threaded holes were tapped into the bars and rings and set screws were used to maintain the joints. This appeared to be fairly effective and the motor was then operated a large number of times without apparent injury. The experience obtained with this cage type of secondary winding was of value in the later development of cage secondaries as will be described. This experimental starting motor was the writer's first real attempt at a commercial split-phase motor. Previous to this, old Tesla polar type experimental motors on hand had been adapted for this starting work, under Mr. Scott's direction. In this particular case, the writer incidentally made some suggestions to Mr. Scott about the possible advantages of a distributed type of primary winding, such as we were working upon experimentally, and he accepted the suggestion so gratefully, that he immediately turned over to the writer the job of producing a starting motor, with the hope that he would produce something materially better than the former type. An interesting comment on this development, is that the customer's operators reported later that this new starting motor was by far the best one that we had yet put out.

In this earlier period, single-phase operation of the induction motor was thus fairly well understood, but it was only in infrequent and special cases that such method of operation was practised commercially. There had been a few cases where small exciters had been operated by single-phase induction motors, and such motors had been used for starting synchronous motors as described. However, it was not generally believed that the single-phase induction motor offered great promise commercially.

Later, however, there were occasional calls for special single-phase or split-phase induction motors, for various purposes. Some of these were so special that manufacturers did not think it worth while to undertake them. In other cases these special machines were built simply because they carried with them other business of a very desirable nature but which was not special. Apparently this was the experience of all manufacturers. In one particular case, which the writer calls to mind, a 25-h. p. high-frequency single-phase motor was wanted for some foreign installation. As the contract included a great deal of other apparatus it was agreed to build this motor.

The writer undertook to build this machine, using a standard polyphase frame and winding, with a special wound-secondary with collector rings, so that resistance could be used during starting. Phase displacement in the primary was obtained by means of reactance in series with one of the primary windings. On preliminary test this motor was most discouraging, as it barely pulled its rated load. Little improvements were then made here and there which helped it out somewhat. However, its overload capacity was relatively small and the machine seemed to be very sensitive at high torques. Its power factor was considered unduly low. However, after several months of effort, it was agreed to send the machine to the customer to meet his immediate needs, with the intent of taking more time and building a better machine for him. The motor accordingly was shipped, and work was begun on the designs for a new more powerful motor. However, before this got into manufacture, word was received from the customer that the motor sent him was very satisfactory in every way. He stated that he had many single-phase motors in regular service, but that this motor was by far the best of all. This, of course, did not mean to us that our motor was in itself an extra good one, but it meant that the other motors which he had must have been pretty poor, from our viewpoint. Possibly we had set our standard too high.

Even before the induction motor was invented, commutator-type single-phase alternating motors had been built and experimented with. The principles of both the series and the so-called "Repulsion Motor" were known back in the latter '80s, and it was also known that they could develop relatively high torques at standstill. Such motors, however, did not have the constant-speed characteristics of the induction motor.

As has already been mentioned, it was discovered in the early years of the polyphase induction motor that it would operate in either direction on single-phase, provided it was once started and brought up to speed, or even brought up part way. In other words its accelerating torque was zero at standstill and increased rapidly with increase in speed. On the other hand, it was known also that the series motor, in its various forms, had just the opposite characteristics, namely, it could develop an accelerating torque which was high at start, but decreased rapidly with speed. It was recognized quite clearly that a combination of these two characteristics would be very desirable for single-phase induction motor work. Prof. E. E. Arnold, of Karlsruhe, combined these properties in his type of motor, this type later being taken up by the Wagner company in this country. In this Arnold motor, the secondary or rotor was in the form of a direct-current armature with commutator and brushes, the brushes being short-circuited on themselves and set in such position with respect to the primary or field as to give the usual repulsion motor characteristics. When sufficient speed was attained, the armature would automatically short-circuit itself at a number of points, thus becoming the usual induction type of secondary. This type, the writer believes, was first put out in this country by the Wagner company, but since the expiration of the fundamental patents it has been built in various forms by many other companies.

In 1892, the writer accomplished experimentally very much the same results in connection with tests on an early synchronous converter. This converter was constructed from a direct-current railway generator, by adding a set of polyphase collector rings over the commutator, leaving part of the commutator exposed, so that direct current brushes could be used when the machine was operated as a converter. Among the various tests made on this machine, was one of self starting by connecting the armature and the series field of the machine in series and bringing it up to speed on alternating current, as a single-phase series motor. When full speed was attained the supply circuit was switched over to the collector rings and the machine operated synchronously with the line. This is simply an early illustration of starting by single-phase alternating current, by means of a commutator and shows that this general principle was well recognized even as early as 1892.

Eventually, various forms of commutator type induction motors were gotten out by different companies. A special type was built by the Westinghouse company but was not marketed, although a number of machines were developed. This consisted of a four-pole-eight-pole primary winding and an eight-pole parallel-wound direct-current type armature winding, with equalizer connections connecting points of equal potential on the armature. The machine was started on the eight-pole combination, with the armature and field in series and when it came up to speed, the field was switched, by means of a centrifugal device, from eight poles to four poles, and the armature automatically became a short circuited four-pole secondary, by means of the eight-pole equalizing connections. This type of motor operated quite satisfactorily on test, and the writer believed it could be made a commerical success. Certain objections were raised against it, such as relatively high first cost (which proved to be unfounded), and

the fact that *the brushes were not lifted from the commutator during normal operations.* This lifting of the brushes was claimed to be an absolute necessity, on alternating-current motors, regardless of the fact that on direct current machines the brushes remained on the commutator at all times. An interesting comment on the above is that recent practise on alternating commutator type induction motors has tended toward allowing the brushes to remain on the commutator. An inherent objection to the machine as constructed, was that it was of the *series* type during starting, and, therefore, was limited to voltages not exceeding 220. However, this type of machine could have been designed and used as a repulsion type, and thus would have been as adaptable for various voltages as any other commutator type induction motor. One advantage of this type was that no mechanical short circuiting device was needed on the armature.

Another type of single phase induction motor with commutator, which was brought out at a later period by the General Electric Company, is known as the repulsion-induction motor. This has a polyphase brush system, instead of single-phase on the secondary. This type of induction motor has been used to a very considerable extent in small sizes. It has no automatic short-circuiting device in its secondary, the circuits being closed through the commutator and the stationary brushes. In this motor the secondary current is commutated at all times unlike the preceding types, which have been described. Practically all these motors, except the Arnold type, belong to a much later period.

The induction motor had received very much study both in Europe and America, and many of the phenomena which are now the usual accepted knowledge, were first described in those early days. For instance, M. Leblanc in France had described and patented the use of resistance in the secondary for increasing the starting torque. Both European and American engineers had also discovered that an induction motor operated on polyphase primary, but with single-phase secondary would run at half speed. Also it was discovered, both in Europe and America, that cascade operation of two induction motors would give the equivalent of an increased number of poles, that is, a lower speed. The writer, with a view to making a polyphase railway equipment, designed and built a pair of two-pole, 25-cycle motors, in 1895, in order to obtain both cascade and multiple operation, for obtaining both half and full speeds. These motors were put on test and operated quite satisfactorily in cascade, and many interesting results were obtained. However, the work was carried no further on account of apparent limitations of polyphase trolley systems.

In the period between 1894 and '98, many odd "stunts" were tried with induction motors. In the literature of that time suggestions appeared, from time to time, regarding various possibilities or experiments and we were always inclined to check them up at the first opportunity. For instance, the half-speed operation obtained by operating the secondary on single phase was tried out, based upon a note which appeared in one of the European papers. The results, however, were not satisfactory due to the relatively poor power factor. Also, as early as 1894, attempts were made to obtain double speed by feeding the supply frequency to both the primary and secondary circuits of the motor. Double speed was actually obtained in this manner at no-load, but difficulty was encountered in attempting to carry any load and finally the test was abandoned.

In these early days it was also recognized that an induction motor, mechanically driven, could act as a frequency changer. The General Electric Company made some very early applications of this scheme.

Also in this early period, it was found that the induction motor would operate as a generator above synchronism. The first real experience of the writer. in this, was in 1894, when he was operating a 75-h. p. induction motor, driving a generator as a load. The motor was operated from a standard polyphase synchronous type generator which was motor driven. During these tests the driving power was purposely cut off the polyphase generator and it was observed that with the induction motor acting as a generator, and held at constant speed, the polyphase synchronous generator continued to operate, but as a synchronous motor, and at a somewhat lower speed than before. Measurements were then taken of the speed conditions and it was noted that when the synchronous generator was delivering full power to the motor, the motor had a speed of from two to three per cent lower than that of the generator; whereas, when the synchronous generator was disconnected from its power source and operated as a loaded motor, it ran at two or three per cent lower speed than the induction motor acting as a generator. This showed, therefore, that the induction motor was operative as a generator *above synchronism with its source of magnetizing current,* namely, the synchronous machine. It was known by the writer at even a considerably earlier date than this, that a synchronous motor could furnish "leading" or exciting current to its generator, and, therefore, it was obvious in this test that the synchronous generator, acting as a synchronous motor, was furnishing the necessary exciting current for the induction motor when the latter was operating as a generator. Quite elaborate tests were then made on this outfit primarily for the purpose of determining the general characteristics of a motor operated in this manner. This ability of the induction motor to act as a generator, was utilized experimentally shortly afterward, in connection with some electric hoisting apparatus which was being developed. The induction motor in these tests was used as a brake, when dropping the load, by operating it above synchronism.

The above illustrations are simply mentioned to

bring out the fact that many of the now well known actions of the induction motor were fairly well comprehended as early as 1894 and '95. In this earlier work there were two polyphase schools, so to speak, namely, the two-phase and the three-phase. The Westinghouse Company was known as the advocate of the two-phase polyphase systems, although it built both; whereas the General Electric Company was considered as favoring three-phase, although it also built both. The fundamental reason for the Westinghouse two-phase was principally in connection with lighting systems. When polyphase generators were first advocated strongly, for general purposes, practically all the service was lighting. With two phases it was considered that there was materially less complication in the smaller number, of feeders, than was the case with three phases, and this was true. It was recognized that the three-phase motor in itself was slightly better than the two phase, but it was felt that the disadvantage of the more complicated supply system considerably overbalanced the advantages in the three-phase motor and in the transmission. However, after a few years, conditions changed materially so that the needs of the polyphase transmission began to overbalance the advantages of two-phase distribution, so that there was a growing call for the three-phase system. It was about this time that the well known Scott two-phase-three-phase transformer system was devised, so that the advantages of the two phase and three phase systems could be combined. However, with the coming of true transmission systems and the further growth of the polyphase work, the three-phase system eventually dominated the market and the induction motor business became primarily three phase. This does not mean that the two phase system was a mistake, for it is probable, that, without this simpler system at the start, the polyphase system might have had more difficulty in making headway. It is simply one of the many illustrations in the electrical engineering field, where a simpler system, initially, has been driven out by a somewhat more complex system which contained greater possibilities in the end.

Nothing has been said yet regarding the 25-cycle frequency. This was inaugurated in 1893 in connection with the first Niagara Falls power installation and was quickly adopted, especially for synchronous converter work. The use of 25 cycles, however, did not have any controlling effect on the induction motor development in the earlier years, although it did have a bearing on certain of the later work, such as industrial plants and steel mill electrifications, as will be explained later.

By 1896, apparently the induction motor had settled down to fairly standard practise. As stated before, this practise covered the use of secondary resistance for starting except in the case of very small motors. The standard General Electric motor of this time was of the stationary primary type, while the standard Westinghouse had a rotating primary. Both motors were quite satisfactory machines, and, as mentioned before, there were people in the Westinghouse company who fully believed that the Westinghouse motor was 100 per cent perfect and could not be improved. However, the writer had his doubts. From time to time, as opportunity occurred, he had done considerable experimenting on cage type secondaries and was somewhat predisposed toward such a construction, provided the starting limitations could be overcome. This was one of the matters upon which he spent his spare time in analyzing and investigating, and finally as a result of his analysis of the characteristics of the motor, he saw a way to obtain the desired result. In those early days induction motors could be designed from calculations in a fairly satisfactory manner, and the effects of reactance, resistance, etc., upon the starting and pull-out torque were fairly well understood. Also crude methods were in existence for calculating the reactance. It was about 1895, while testing an experimental motor for hoisting purposes that the writer noted that, in this particular motor, very large starting torques were attained, although the motor had a pure cage winding in the secondary. Here was something worth following further, to find the fundamental reasons for this extremely good result. About this time the writer was working over the vector relations of the induction motor with a view to obtaining better methods of analysis and calculation. He found that by taking given motors and showing the various relations graphically, he could produce various points on the actual speed torque, current-torque and various other curves of the motor. This was a slow and laborious process, for a complete diagram had to be constructed for each point. After checking a number of machines and reproducing their characteristics, he then began to study special cases and among other things, he varied the reactance, *on paper*, over a wide range and found that if this could be reduced in a given machine, below a certain value, then not only good pull-out torques, but correspondingly good starting torques could be obtained *with permissible slips for constant speed work*. This was most interesting and several cases were checked up where unexpectedly high torques with cage windings had been found, especially in the case of some of the experimental motors already mentioned. The results showed that these were motors of small reactance, and they indicated, furthermore, that *sufficiently small reactance was actually obtainable in motors of commercial proportions with cage type windings*. This was most interesting as showing the possibilities for the development of a cage type motor for general power purposes. The writer then went into the analysis of reactance conditions most fully, and spent months partly in daytime, but mostly in the evenings, analyzing magnetic conditions, with a view to predetermining all the "leakages" or "stray fields", etc., and checking with existing machines. It developed, in time, that

he could reproduce, by calculation, the reactance conditions of practically all the existing machines. Also he took up the question of reducing the reactance fluxes to a point which would give relatively large starting torques with cage wound machines. In the early stages of this work he gave up the graphic method of solution, by transforming his diagram from graphics to a set of mathematical equations, derived directly from the geometry of the vector diagrams. With this set of equations he was able to produce quite quickly a complete set of characteristic curves of any motor. Also to obtain any desired starting and pull-out conditions, he could very quickly determine the limiting value of the reactance necessary. This work showed very definitely that it was entirely possible to produce a commercial line of polyphase induction motors with *pure cage type secondary windings with starting torques up to two or three times the rated torques* of the machines.

With these data available, it was decided to undertake to build commercial induction motors with cage secondaries. Motors of 20, 30 and 50 h. p. were first undertaken. All were brought through *from calculation* and all developed the expected starting torque conditions, namely, about two and one-half times the rated full-load torque and from three to three and one-half times pull-out torque. This was considered a most remarkable result at the time, as it had been generally held that cage motors could not develop, very high starting torques. In conjunction with this work, there was another fundamental departure from older practise, namely, in the use of voltage reducing transformers in connection with these motors. While these cage type motors could develop starting torques of from two to three times rated load, they also required starting or "line" currents of six to nine times full load current which was considered a prohibitive condition. Naturally the suggestion arose to reduce the starting current, and the starting torque proportionately, by the introduction of a small transformer at start, so that the motors would take not more than three times full-load current from the line when starting full-load torque, while at full speed they would be switched to the line voltage and would have the corresponding full-power characteristics. This was the origin of the auto-transformer or "compensator" method of starting.

Naturally the use of cage windings pointed directly to an inversion of type in the Westinghouse machines; that is, with the cage construction, the secondary or cage winding should naturally be placed on the rotor, in order to do away with all collector rings or other rotor connections, the stator winding being placed on the primary. These new motors were built in this manner and a few of them were put in service in 1896, in order to obtain some practical experience. Steps were taken immediately to carry the development below 20 h. p., in order to have a reasonably complete line. This line was gotten out in fairly complete shape in 1897 and was pushed actively during that year. At first this type of motor was received with a good deal of doubt, especially by technical people. Operators, however, especially in industrial plants, took to this type of motor on account of its substantial simplicity, and, in spite of many criticisms, they bought more and more of such motors until, in a short time, evidence began to show that this type was liable to take possession of the field. In fact many users of this motor would consider no other type. This line of cage-type motors was known as the Westinghouse type *C*. When first put out, it was criticised as containing a most palpable absurdity in the fact that no cage type motor could develop high starting torques, and yet here was a cage type motor with a reducing transformer for lessening the torque at start. What could be more absurd? A not uncommon statement at that time, in referring to the inadequacy of any kind of electrical apparatus, was—"It is as bad as the Westinghouse type *C* motor."

However, in time certain people awakened to the fact that this motor was able to develop the necessary starting torque, for the customers were thoroughly well pleased with it, and here and there it was used in places where the starting conditions were known to be very severe and yet it met these conditions quite satisfactorily.

However, while the real development in the cage-wound motor came as above indicated, yet there are numerous evidences of earlier work having the cage type of construction in mind. For instance, among the writer's specifications is one dated May 16, 1893, calling for an induction motor with a solid cast iron rotor core with 48 slots, and with the winding of "poured-in" copper, forming a complete copper cage.

Also as described before, in connection with a single phase motor for starting a synchronous motor, various types of secondary construction had been attempted. In building the high-torque type *C* motor described above, the secondary was first made with a simple bolted construction for attaching the secondary bars to the end rings. However, in the first 50 h. p. motor brought through, very severe starting tests were made, the motor being repeatedly started from rest under heavy torque, during many hours. At the end of this test it was noted that the per cent slip for large torques had increased considerably. The bolted secondary construction was then examined, and it was found to be defective in that expansion of the copper bars and end rings, due to changes in temperature, had actually stretched many of the bolts until the contacts were loose, and in some cases the bolts were broken. This looked like a most serious defect. However, one of the testing engineers, Mr. R. S. Masson, then made the suggestion that this trouble might be overcome by using heavy spring washers under the bolts, simply to take care of expansion and thus maintain good contact of the bars with the rings, regardless of tem-

perature. This was immediately tried, and the former test repeated, which resulted in no loose or broken bolts. This construction was then adopted as standard practise and was used for many years. However, it was difficult to get the manufacturing departments to understand the function of these spring washers, being prone to believe that they were purely to keep the nuts from turning loose.

Other companies also found it necessary to adopt this spring washer construction for maintaining good contact. This construction eventually went out of use in favor of cheaper types and not through operating defects in the bolted construction itself.

This cage type construction soon led to some very interesting developments and it was found necessary to obtain quite definite resistances in the secondary winding for giving the required torque, current and speed conditions. In consequence, as the secondary bars themselves were usually of copper, it was found necessary to vary the resistance of the end rings by using various alloys. Iron was tried, both cast and wrought, but usually with harmful results. Various bronzes, brasses, etc., were also tried, and in time quite a choice of materials became available for end rings. Moreover, it became usual practise to vary the resistance of the end rings of individual motors by slotting one or both of the rings radially to a certain depth, thus virtually lengthening the current path. This apparently did no harm and was quite effective in increasing the resistance of the rings, a range of possibly 100 per cent or more in resistance being obtainable in this manner.

This type *C* motor was not quite as efficient as later types, but it was of such sturdy construction and has such a high thermal capacity, compared with former constructions, that it obtained an almost undesirably good reputation in some ways. For instance in service, it could be pulled to standstill momentarily by a heavy overload and upon removal of the load, would immediately recover to full speed with no apparent injury, except in extreme cases. This was because the motor at standstill, on full voltage, had a starting and accelerating torque of two or three times the rated load. On account of these interesting, and, at that time, unusual properties, many people obtained an exaggerated notion of the motor's capabilities. For example, some of the Westinghouse people wanted to advertise that the type *C* motor could not be burned out, based upon certain experiences of the above nature. The writer, however, warned repeatedly that this was not a fact, but that the motor could be burned out just as surely as any other type of machine *if overloaded for a sufficient length of time.* He insisted that this motor, while a very good one, could not accomplish the impossible and that any claims that the motor could be overloaded to any extent without injury were dangerous and liable to react upon the manufacturer sooner or later.

These type *C* motors, in some cases, had pull-out torques of four times their rated capacity, and starting torques of three times their normal running torques. In consequence, due to the general shape of the speed torque curve, a sudden application of very heavy load would not easily jerk them out of step, so to speak, as was the case with the earlier types. In many of the motors of that time, a drop in speed of ten to fifteen per cent, due to sudden heavy overload, would bring the motor down to a decreasing torque so that it would very quickly pull down to rest. This condition is illustrated by Fig. 8.

Partly on account of the shape of the speed torque curve and partly due to the great thermal capacity of the type *C* motor, it acquired a reputation for sturdiness, reliability and capacity, held by no other motor before or since. This was a very good thing in those early times, when this type of motor was establishing itself, but in later years it has been recognized that some of these characteristics can be partly sacrificed to advantage, in order to favor other characteristics, such as efficiency, power factor, reduced dimensions, etc. In consequence, while the general characteristics of the type *C* motor have been retained to a greater or less extent in all general purpose cage motors of later times, yet a compromise has been made between the various characteristics, in order to give the most satisfactory all around results, with our later more accurate applications of motors to their service.

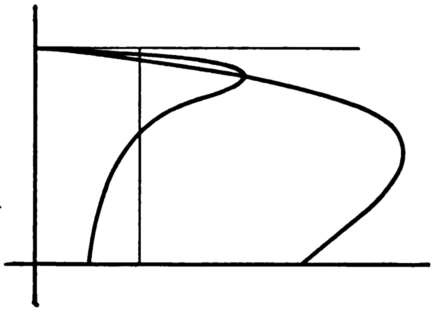

Fig. 8

It was not long after the cage-wound motor was put on the market until rare instances were noted where the motor, when used where speed reversal was necessary, would not reverse, but would continue to run in the same direction as before, (but at a much lower speed) when the primary terminals were reversed. The reason for this was not understood at the time, but investigation showed that, in each case of this sort, both in numerous shop tests and in outside instances, the relative resistance of the secondary end rings, compared with the secondary bars, was low. As a direct result of this, the end rings of such motors were slotted to increase their resistance compared with the bars; and in every case where this was done the motor would then reverse in a satisfactory manner.

This effect was noted as early as 1897 and '98 and is now recognized as due to the well known "cusps" in the speed torque curves of such motors, as shown in Fig. 9, but, at that time, the whole matter was more or less of a mystery. The writer recalls that in 1900 a prominent European engineer mentioned to him that the A. E. G., of Berlin, had claimed to have encountered cases where induction motors failed to reverse, but he said that he believed it to be theoretically and practically impossible. He was then informed that we had encountered similar difficulty in a number of cases and that there was no question about it,—it could happen. It was also explained to him that all cases of this sort, which we had investigated, were of the cage type and the relative resistance of the end rings in such cases was considerably less than that of the bars, the trouble being corrected by increasing the end ring resistance. He then remarked that as we said so he believed it, but he did not understand how it could be.

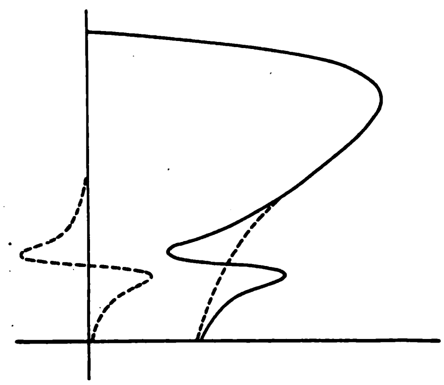

Fig. 9

In the analysis of the magnetic conditions, leading up to the development of the cage type of motor, as already described, the writer did much work in, plotting and analyzing the flux distributions and obtaining the magnetic "field forms" in the induction motor, during the cyclic changes. He investigated the effect of "chorded" or fractional-pitch windings and found their influence upon the magnetic distributions, reactances, etc. and incorporated expressions in his formulas for covering such windings. He determined that more uniform magnetic fields could be obtained by the use of such windings and that the most uniform effect was obtained when the span of the coils was shortened by an amount corresponding to half the width of one phase belt. Also the advantage of chorded winding, in giving the equivalent of a fractional number of wires per coil or slot, was worked out at that time and this feature has been used since to a very great extent.

The use of a fractional-pitch winding had been proposed and patented by the writer, in connection with commutation of direct-current machines, but in this the function of the chording was to reduce the reactance of the coils undergoing commutation. In the induction motor a somewhat similar reduction in reactance was accomplished, but this was not considered as the primary object in chording. The saving in the length of the coils, better flux distribution of the main field and the ability to obtain the equivalent of a fractional number of turns were all considered of more importance. This improvement in induction motor windings was also patented about this period.

It was along in the period from 1894 to 1898, that the writer actually constructed multispeed motors, by changing the number of poles in a given frame, as distinguished from cascade-parallel operation. This had been talked about a great deal, at different times, but there had been no occasion to build such motors. However, in some preliminary considerations for electrifying a certain large railway, the possibilities of polyphase current were taken up. Mr. Westinghouse suggested that a pair of induction motors be built with a view to determining whether satisfactory characteristics were obtainable for railway work. In order to simplify the outfit, motors with cage secondaries were considered and two large motors were built for four poles and 25 cycles. These motors were made with very high starting torques,—about six or seven times full load, the reactance being made purposely very small, so that the motors could have relatively small slip at full load and yet develop very high starting torque. It was the intention to control the speed during starting by varying the voltage supplied to the motor, an induction regulator being used for this purpose. Two motors and a regulator were built, but the system was found to be quite unsuitable for the purpose, partly due to the fact that only one speed was available. To overcome this, the writer then devised an arrangement for recoupling the primary winding to give eight poles as well as four. This was then tried out and it was found that both the four and eight pole speeds were quite effective. As far as the writer remembers, this was about the earliest large work in pole changing.

Among other objections raised against this proposed a-c. railway system, was the use of two trolley wires. The suggestion was made that such a system should really be single-phase. With this in view, as an experiment, the writer then operated one of the two special railway motors across *one phase of the supply circuit* and from it, as a phase converter, fed polyphase current to the four-pole-eight-pole motor. The tests showed that this latter machine, operating as a polyphase motor, acted quite satisfactorily on both the four-pole and eight-pole combinations. This, therefore, was an anticipation, experimentally of the split-phase traction system, which came out many years later. This feature of transforming from single-phase to polyphase by means of an induction motor, however, was not new or unknown at this time; for it had been brought

out very clearly by the General Electric engineers, in connection with the monocyclic system already mentioned, that if the monocyclic supply system could once get a large induction motor in the system up to speed, this motor would be of direct assistance in the starting of other motors, due to its phase converting qualities. It had even been claimed that with one induction motor up to speed, the "teaser" circuit of the monocyclic generator could be cut out, and the induction motors themselves would maintain the polyphase characteristics, provided all the phases were tied to the circuits. Thus it was known very early that the induction motor possessed these "phase-splitting" characteristics. The above tests for phase splitting with a polyphase railway motor are interesting merely as an attempt to obtain railway operation in this manner and also as early anticipation of much later practise.

The introduction of the cage type secondary, had a considerable bearing on the development of multi-speed motors, for a properly proportioned cage secondary could operate fairly well with various combinations of poles; whereas with the "polar" type of secondary, one winding was suitable for only one speed, without considerable reconnection, which was not convenient in practise with the relatively small motors in common use in those days.

Shortly after the above experiments with the two sets of poles on a railway motor, the writer designed various two-speed and three-speed induction motors for special purposes, some of which are in operation at the present time, after more than twenty years. An interesting and curious incident occurred in connection with one of these early commercial motors. A two-phase two-speed motor for four and eight poles was designed and built, using a single primary winding which was recoupled for change in poles. On this motor some mistake was made in the primary connections and it was discovered that, under certain conditions of switching, an effective twelve pole speed was obtained. This was not on the program, and was considered quite interesting and an attempt was made toward investigating the reasons for it. It was realized that this result was due to some mistake in the internal grouping of the coils and the writer set about determining the cause. However, before a proper examination of the winding itself was made, the winding department men got hold of the machine, and, knowing that there was a mistake somewhere, they disconnected the winding completely and reconnected it. Thereafter the machine would not show the twelve-pole speed, and neither could the shop men give any explanation as to what changes were made. Thus we were unable to make any complete tests or any investigation in the actual machine to find the reasons for this curious speed combination, and, furthermore, we were never able to work out a possible combination which gave the three speeds, as shown in the preliminary tests. Here, therefore, was a lost characteristic or combination, which might have proved useful, but which, on the other hand, on more complete tests, might have proved unsatisfactory. The writer took up the study of this problem at odd times during the next year or two, but eventually gave it up. It, therefore, stands on his records as one of the mysteries or unsolved problems in his engineering work.

The period from 1894 to 1900, might be called the "Golden Age" of induction motor development. Nearly all the things that have been developed since, originated or were first put into practical use during this brief period. During this time the induction motor business was practically revolutionized by the introduction of the cage winding with high starting torques. In this period the polyphase motor became so thoroughly established as a commercial device that it was already taking the offensive against its d-c. rival. During this time the theory of the induction motor was worked out and applied in practical forms of calculation, and the methods of calculation, developed in that time, hold with slight modification until today. The method of analysis and calculation derived by the writer in connection with the development of the cage tyye motor, as already described was used throughout the following years by the Westinghouse engineers and is the basis of their present methods. In the General Electric Company the methods devised by Dr. C. P. Steinmetz, during this period, are also used very generally throughout that company. These methods are naturally closely related to each other, although expressed in somewhat different form. The writer's paper "The Polyphase Motor," presented in 1897 at the convention of the N. E. L. A. at Niagara Falls, which is a non-mathematical exposition of the subject, was a direct outcome of his work on the cage type motor and his methods of calculation, and many of the curves shown in that paper were derived directly from his formulas.

Among the early analysts was Mr. B. A. Behrend, leading technical expert of the Bullock Company and later of the Allis-Chalmers Company. His early book on the induction motor was an exposition of fundamental principles and practises well worthy of study now, after twenty years, even with the great advances and developments in the art.

Indeed, this period might be called the "Age of Induction Motor Analysis," as well as development, for practically all the modern analysis is based upon fundamentals developed during this time. All the analytical work was not published, but the methods of those times were carried into the practical fields, with marvelous results, and it may be said that the methods of today are largely refinements of those of twenty years ago. These refinements in methods

have led to refinements in the machines, but not to any new principles which have allowed any radical departures in types.

By 1900, the induction motor had become pretty thoroughly established, with the cage type of construction far in the lead of all others. In fact, the enthusiasm for this type was so great that in some applications it was used where the wound-secondary type would have been superior. It took time, however, to determine its true limitations and its handicaps.

The period beginning about 1900, was one of application rather than of new developments of the induction motor. In Europe, the Ganz Company was applying the induction motor to locomotive work, in Italy. Eventually Mr. Westinghouse bought the American rights of the Ganz patents, but never used them. However, in this country one early attempt was made at electric traction by polyphase current, namely, on the Miami & Erie Canal near Cincinnati, by substitution of small locomotives for mules for towing the canal boats. A track was laid along the banks of the canal and two overhead trolley wires were installed. The locomotives were of comparatively small capacity and each was equipped with two three-phase motors adapted for cascade-parallel operation. The overhead voltage was 2000 and step-down transformers were placed on the locomotives.

In operation these polyphase electric locomotives did all that they were expected to do, and yet the installation was a failure, due to reasons outside of electric operation. In the first place it was intended that each locomotive should pull a series or "train" of canal boats, but in practise this was not feasible, at least on this particular canal. As the engineer on the job reported, the first boat of the train "piled up" the water ahead of it, thus lowering the level behind, the second boat did the same, and the fifth or sixth boat, in consequence, was dragging in the mud. In other words, the train of canal boats acted somewhat like the old fashioned chain pump.

A second trouble reported, which, however, was not necessarily a fatal one, is amusing in showing how the effects of little things sometimes are unforeseen. In the days of mule towing, the mules kept the grass down, along the tow path. However, with electric towage the grass grew so high that the locomotive pushed it over on the rails where it acted like a good lubricant so that, in some instances, the traction diminished to almost nothing. This trouble, however, could have been overcome, in case that the boat-towage had been more successful. After operating this system for a short time it was abandoned as impracticable.

Some years later, the General Electric Company installed polyphase locomotives in the Cascade Tunnel of the Great Northern Railway. These were three-phase, 25-cycle, 1200 to 1500 h.p. equipments and were used primarily for hauling trains through the tunnel. A single speed, with rheostatic control, was used on this electrification. An interesting feature was the use of 6000 volts on the two overhead wires.

At a still later period, three phase locomotives were installed by the General Electric Company along the Panama Canal, for towing purposes. This latter is the largest application of polyphase current to traction in America.

Beginning about 1896 and '97, steps were taken to apply induction motors to crane and hoist work. Among the earliest crane applications, were cage-wound induction motors with high-resistance secondaries and with means for supplying variable voltage to the primary windings for obtaining speed control. Quite a large number of crane equipments of this type were installed and the writer believes that some of them are still in operation. However, in general the polyphase motor for crane work has never been considered as fully competitive with direct current, due to the greater complexity required in polyphase crane trolley systems.

In the same way early attempts were made to apply induction motors to hoisting work. Both cage type motors and wound-secondary types were tried out and in some cases both were successful, in other cases both were failures, due, however, to misapplication in some instances. In later years more success attended such application due to a better understanding of the problem.

Induction motors quite early were applied to elevator service, especially for freight elevators. In the early days a high-resistance cage secondary was the preferred type and, in many cases, for low-speed service, such motors were thrown on and off directly without any control apparatus. Gradually, however, the opinion grew that the cage type motor did not fit such application as generally as the wound type. Quite recently there is a return to the squirrel-cage type, but with pole changing for two speeds.

About 1900, the induction motors began to extend to quite large sizes. The self-starting synchronous motor had not come yet, to any extent, and, therefore, practically all large power applications were through induction motors. These began to appear in 500, 1000 and 2000-h.p. sizes, sometimes of the cage secondary type, but quite frequently with wound secondaries; for the starting problem was recognized as of more or less controlling importance in these large motors. It must be remembered that in this period the present huge power plants were not even dreamed of, and generators of 2000 or 3000-kv-a. capacity were considered quite large. In consequence, the starting of a 2000-h. p. motor, especially if it was necessary to develop considerable torque, was a matter of much importance, for the reactive effects on the generator were liable to be serious, if not disastrous.

Power Factors

Almost from the first, it was recognized that the induction motor, in its normal form, would always have a power factor considerably less than 100 per cent, due to the fact that its magnetization was represented by

a reactive current drawn directly from the supply system, and, therefore, at full voltage and full frequency. It was also known quite early that the so-called magnetic leakages or stray fluxes gave reactive e. m. fs. which affected the power factor. However almost as soon as the designers began to calculate the induction motor characteristics, it was noted that the smaller the number of poles, the lower would be the magnetizing current. In fact, this was obvious from their knowledge of direct-current design. Consequently it was soon recognized that 25-cycle motors with their smaller number of poles, would require less magnetizing current than 60-cycle motors, and, therefore, such machines would naturally show higher power factors, due both to the smaller magnetizing current and the low reactance voltages. Consequently, in the earlier days the 25-cycle motor was looked upon quite favorably, due largely to its better performance This was particularly true where low speeds were desired, requiring motors with a relatively large number of poles. In the early days, in many of the larger applications, direct connection was considered as most desirable and, in consequence, relatively low speeds were required. In consequence, the frequency of 25 cycles was favored for industrial plants, due to the more suitable characteristics of the induction motors. In fact, this had a predominating influence in fixing the steel mill standard of 25 cycles, which was adopted nearly twenty years ago, after careful consideration by the steel mill engineers. In those days, many of the heavier steel mill operations called for speeds of less than 100 rev. per min. on the motors and this was considered prohibitive for anything but 25 cycles. Largely on this account, but also for other reasons, this frequency was adopted as the standard. However, at the time, this seemed to be very much in line with other practise, for central stations, transmission systems, railway systems fed from synchronous converters, etc. were all tending toward 25 cycles.

In steel mill work, in those days, heavy gears were looked at askance. However, in time, cases came up where gearing was desirable and with the need came the development of good reliable gears, so that in later years there has not been the same necessity for the low-speed induction motor as was formerly the case. In consequence, the tendency has been toward higher speeds with proportionately smaller number of poles, and, therefore, toward conditions which could be well met by 60 cycles. Furthermore, due to various causes, particularly the development of the 60 cycle synchronous converter, the general trend of the power systems throughout the country has been toward 60 cycles for both generation and transmission. In consequence there is some question today whether the old steel mill standard is not becoming obsolete. The interesting point, however, that it is intended to bring out, is that this choice of standard for mill work was fixed very largely by the induction motor design itself.

While the power factors on the early induction motors were quite good, yet when the type *C* motor came out, the quite remarkable results in power factor obtained with 25 cycles, was a subject for doubt and criticism at first. For instance, in a paper on the polyphase motor, delivered in 1897, before the N. E. L. A. Convention at Niagara Falls, the writer showed power factors as high as 95 per cent on certain 25 cycle polyphase motors. After the meeting, certain designing engineers, privately discussing the matter with him, said that this high power factor looked well on paper, but could not be obtained on actual test. The writer replied that the published results were obtained from actual test, and that they checked with the calculations. The critics then stated that if such was the case, they would accept the results as actual facts, but they considered them most marvelous.

In those days, power factors were not usually looked upon as simply representative of certain reactive components, and naturally it was not recognized by most people that a 95 per cent power factor represented a 31 per cent reactive component, whereas a 90 per cent power factor represented only 43½ per cent or only about 40 per cent more. A jump from a 90 per cent power factor, which up to that time had been considered quite good, to 95 per cent did really seem a marvelous and almost unbelievable result and yet, in fact, did not actually represent a very great reduction in the total reactive component. Even today many people think too much in terms of power factor rather than reactive component and are misled accordingly in many matters of importance.

Naturally, engineers quite early turned to the question of eliminating the reactive component in the induction motor. The possibility of reducing the magnetizing current quickly forced manufacturers to very small air gaps. In the very early motors a total gap of ⅛ in. ($^1/_{16}$ in. on each side) seemed extremely small and the manufacturing departments grudgingly accepted such narrow limits. However, before very long, and with more manufacturing experience, the air, gaps began to diminish until $^1/_{32}$ in. clearance on each side was considered quite satisfactory even in moderately large motors.

One of the first engineers to attempt to reduce the reactive component supplied from the line, was M. Leblanc, the well known French engineer. He proposed to supply the magnetizing current to the secondary of the motor instead of the primary, by generating in an auxiliary machine in the secondary circuit, suitable out-of-phase e. m. fs. which would circulate exciting currents in the secondary winding of the motor. Heyland, in Belgium, accomplished similar results by means of a commutator on the secondary circuit of the motor itself, by which the primary frequency could be converted to the secondary frequency at very low voltage, compared with the primary. Neither of these schemes, however, persisted for any length of time in Europe and neither of them were adopted

in America, at least not until many years later. Both of them involved the commutation of alternating current and, in the early days, this was considered a more serious problem than the reactive component of the motor input. In later years, many attempts have been made, and many schemes devised, in connection with correction of power factor of induction motors, but none of these have as yet come into general use, for they all involve the commutation of alternating current. This means complexity in the design of the induction motor, which apparently has not yet been accepted by the public in general. Gisbert Kapp, and Miles Walker, in England, have developed practical types of "phase advancers." Kapp's device has been tried out experimentally in this country by the Westinghouse company, while Walker's was built by the British Westinghouse company. The General Electric Company has tried out a form of the Leblanc phase-correcting device.

Developments from 1900 to 1910

The decade following 1900 was very largely one of growth as distinguished from development. In other words, the induction motor came in so rapidly and business was relatively so large that the manufacturing companies were busy extending standard lines rather than producing new types. This was a period of growth in size as well as in quantity. Also, due to greater refinements in application, etc., manufacturing companies were getting ready with new lines of apparatus, having improved characteristics, less weight, etc.

During the period from 1895 to 1905, the Westinghouse company, as well as other companies, had built many alternators with partially closed slots. In consequence, this construction was also carried into induction motor primaries and secondaries, so that the merits of partially closed slots were well known in the way of decreased losses, improved power factors, etc. However, practically all the moderate size and smaller induction motor primaries had been made with open primary slots, the "closed-in" slot construction appearing only on the larger machines. In attempting to obtain the merits of the partially closed slot machines for moderate and small size machines, the Westinghouse company developed a new line of motors called the type *CC*. This type had form-wound coils, without insulation except on individual wires, which were fed in through openings at the top of the slot. The insulation in the slot was a special cell. The end windings were then taped after being placed on the core.

This line of machines was about ready for the market when it became apparent that a somewhat lighter and smaller machine was desirable. In consequence, almost at once this new type was reconstructed, both mechanically and electrically, to form the type *C C L* line, which was then put on the market. This was the first radical departure from the type *C* line. It had many of the characteristics of the type *C* motors, but its efficiency and power factor were materially better. This line was on the market for a number of years, but it was found that many customers did not like the dropped-in type of winding, with partially closed slots, as repairs were more difficult than with the former open slot construction such as the type *C*. Moreover, when exposed to severe conditions of moisture, dirt and other foreign materials, the insulation on the end windings was assumed to be less satisfactory than the type *C* with its competely insulated coils. This condition, however, later was improved materially by dipping the end winding into insulating gums and varnishes. However, after a few years, with this type of winding, it developed that the operating public in general would be willing to sacrifice certain characteristics, to a slight extent, in favor of easier types of construction requiring less expert skill in repairs. In consequence, the open type of primary slot then came into general use in later constructions. This is not true, however, of the small sizes, for here the gains, due to partially closed slots, have been so great that they have apparently much more than offset the problems of repair, so that the trade in general has accepted the partially closed slot for the smaller motors.

In attempting to combine the advantages of the partially closed slot with those of the open slot construction, many manufacturers of induction motors, including the Westinghouse and General Electric companies have sought to develop and use some form of magnetic retaining wedge, which would serve to hold the primary coils in place and, at the same time partially close the slot magnetically. During the past ten years, many forms of wedges have been devised and many motors have been built with such wedges, and, within their limitations, several forms of these have given quite satisfactory results. In fact, this is still one of the active development problems in several of the manufacturing companies.

Speed Control of the Induction Motor

In applying the induction motor to steel mill work, many new problems have come up, and many new and unusual developments have occurred. Among the problems involved was that of obtaining speed adjustments, or variations, in an economical manner. Inherently the induction motor is a constant speed machine and has been recognized as such almost since the first. This being the case the motor has been applied with this limitation in mind, and, in consequence, there have been certain classes of service where the induction motor inherently does not fit well. Adjustments in speed in such cases must be obtained either by the use of some other kind of motor or by some mechanical means. However, in steel mill work, where large powers are involved, these indirect means have not been applicable, in many cases. Direct-current motors in large sizes are not desirable on account of voltage limitations, and

mechanical speed-changing devices on a large scale do not appear to be applicable or feasible. In consequence, pressure has been brought, by the needs of the situation, to develop means for obtaining the necessary speed adjustments or variations with induction motors.

Adjustable speeds, of course, are obtainable with induction motors by varying the supply frequency, but this is not a general solution as it involves means for obtaining variable or adjustable frequency, which usually contain the same difficulties as speed adjustment in the induction motor itself. Speed control is also obtainable by varying the number of poles in the motor, but obviously this is limited to a relatively small number of combinations, and fine graduations in speed are not obtainable. Speed control is also possible by means of a resistance in the secondary circuit, but speed changes obtained in this manner are uneconomical and the speed varies with changes in torque. However, if instead of expending energy in resistance in the secondary circuit, such energy is expended in some useful way such as in a motor, or other devices which can either utilize it or return it to the system, then economic speed control becomes possible. However, with each change in speed in the secondary circuit of the motor there is a new frequency and a new voltage and, consequently, any means for absorbing the secondary energy must be of a kind which is adapted for adjustable frequency and voltage. Obviously, therefore, we have simply transferred the variable frequency problem from the primary to the secondary, with this difference, however, that the secondary frequency is proportionate to the slip, and, therefore, for moderate slips on either side of synchronous speed the frequency involved will be relatively low. This is of direct importance, because a number of the practical means for furnishing low frequency are dependent upon alternating-current commutation, which, in general, holds certain relations to the frequency.

In some of the earlier mill work, where only two speeds were called for, either cascade operation of two motors or pole changing in one motor was resorted to. In 1906, the Westinghouse company installed a relatively large cascade set in the Illinois Steel Company, at Chicago. This set had twelve poles in one frame and twenty-four poles in the other, and was adapted for operation at speeds corresponding to 24 and 36 poles. This set is still in operation after fourteen years.

However, the cascade arrangement proved to be expensive compared with the use of two combinations of poles on one frame and in later work, requiring two speeds, single frame motors were installed as a rule, with their windings adapted for giving two sets of poles. Some very large motors of this type were installed in steel mills by both the General Electric and Westinghouse companies.

However, it gradually developed, both in Europe and in this country, that finer gradations in speed were necessary and, therefore, various methods were developed for obtaining close speed adjustment. Most of these methods were tried commercially in Europe before they were undertaken in this country, but, in recent years, practically all the available methods have been tried out commercially in one form or another in this country. The methods of speed control by utilizing the loss in the secondary may be considered as primarily three in number; (1) by converting the secondary frequency and power to direct current; (2) to mechanical power; and (3) by converting the variable secondary frequency to some definite constant frequency, such as the primary, by means of a frequency changer.

The first of these methods, utilizes a synchronous converter in the secondary circuit, converting to direct current, but at a variable voltage. This power can then be utilized by an adjustable-voltage d-c. motor. This method usually known as the Kraemer, had been much used by both the Westinghouse and General Electric companies.

The second method involves the use of a variable frequency motor, which of necessity is a commutating type a-c. machine. The variable-frequency secondary power is thus converted directly to mechanical power, in which form it can be utilized in various ways. This arrangement, known as the Scherbius, has been used quite extensively by the General Electric Company.

The third method involves the use of a frequency changer, which is also a commutating type machine. This method is practically the equivalent of the first method above, except that it transforms from one frequency to another instead of to zero frequency (direct current). This third method has been used recently by the Westinghouse company.

It may be noted that all these methods involve the use of extraneous devices for regulating the speed and, therefore, it may be said that this development should not be classed with the induction motor problems, but is really a control problem. In consequence, it may be said that this need for adjustable speed has not really affected the induction motor development itself, but has simply extended its field of operation, and has given to it some of the flexible characteristics of the direct-current machine, but at the expense of considerable complication.

Heavy Power Applications

Steel mill work is a good illustration of what happens in extending electric power application into heavy work. Originally the steel mill applications were largely direct-current, which presented the greatest flexibility in the motors themselves. However, before long, it was seen that the power requirements in general would overtax the direct-current type unless abnormal

voltages were used, and, in consequence, the trend was soon toward the alternating current, simply because of its capabilities in large powers and its flexibility as regards voltage. This had been the trend in many other lines, such as power station work, railway work, etc. Long ago the direct-current power station for railway work became obsolete and alternating current generation, with synchronous converters in distributed substations, took the place of the former direct-current power generating stations. In central station work, in general, the alternating-current system had driven out the direct-current type so long ago that the present generation knows practically nothing else. In direct-current generator work, machines of from 3000 to 5000 kw. have been considered as monsters, but in the alternating current work, single generators of 30,000 kw. are not uncommon. Therefore, the direct current system with its greater flexibility in speed control, etc. has not been able to hold its own against the alternating system with its greater flexibility in voltage transformation. This trend followed naturally into the steel mill business, for here motors up to 6000, 8000 and 10,000 kw. came into use many years ago and the need for such huge capacities has forced the situation to the alternating-current system throughout. When these huge horse-powers are referred to, it must be borne in mind that, in some cases, these also represented very low speeds, such as seventy-five revolutions. An 8000-h.p., 75-rev. per min. mill motor, represents almost the acme of design in induction motor work. Here the mechanical problems of construction may dominate the electrical. Such machines not infrequently have been made with purely engine type frames, similar to engine type alternators, which construction necessitates relatively large air gaps compared with other kinds of induction motor work. A total gap of ¼ in. could seem prohibitive in induction motors, yet such gaps and even larger have been used in some of these huge steel mill motors, as constructed by the larger manufacturing companies. Such machines are especially interesting when constructed for two speeds, usually involving two sets of windings in both the primary and the secondary elements.

Induction Motors in Railway Work

As already mentioned, the General Electric Company applied the induction motors to railway work in connection with the Cascade Tunnel on the Northern Pacific Railway. A much more recent application of such motors to railway work is the Norfolk & Western application at Bluefield, West Virginia. Here the induction motor appears in two radically different functions; one as a generator of power, in the main locomotive motors themselves, and the other as "phase generators" in the so-called "phase converters" which serve to transform from the single-phase trolley system to the three phase circuits for the motors.

As mentioned before, even back in the days of the monocyclic system, induction motors were used for "balancing" polyphase circuits. It was found in the very early days of the induction motor, (the writer does not know who first made the discovery) that when an induction motor was operated at full speed, on one primary phase from the supply system, polyphase circuits could be taken from the machine by simply tapping in on all the primary phases of the motor. In other words, if one phase or terminal of the motor should be disconnected from the line, that phase or terminal would still be active as far as voltage and phase generation was concerned. This principle has been applied many times, and in various ways, within the past twenty or twenty-five years. As mentioned before, the writer tried this method experimentally for operating a polyphase railway motor from a single-phase circuit, in the later 90's. Alexanderson also proposed this general scheme for railway work about twelve years ago, and the General Electric Company made elaborate tests on an experimental equipment. The scheme used on the Norfolk & Western locomotives

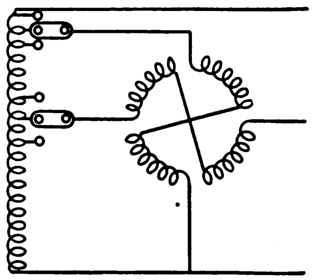

FIG. 10

is based on the same principle. In these locomotives, the phase converters are simply high-capacity induction motors connected to the circuit in such a manner as to transform from a single-phase supply system to a practically balanced three-phase motor system. The phase converter has a two-phase primary winding with a cage secondary. One of the two-phase windings connects across the secondary circuit of the step-down transformer, while the other phase has one terminal tapped to a mid-point of the transformer, thus forming the equivalent of the Scott transformer system. The two terminals of the transformer and the remaining terminal of the phase converter thus form a three-phase system, the proportions of the two windings on the converter being such as to give practically balanced three-phase relations. To compensate for unbalanced conditions with change in load, the tap at the middle of the transformer can be shifted back and forth a certain amount.

Induction Motors in Ship Propulsion

Another huge application of the induction motor, of quite recent date, is in the propulsion of battleships. This started only a relatively few years ago with the electric propulsion of the collier *Jupiter*,

by the General Electric Company, under the supervision of Mr. Emmet. This it might be said was an experimental equipment in the sense that its purpose was to find whether electric motors were suitable for the propulsion of large vessels. Based upon these results the Navy went into electric ship propulsion on a large scale so that at the present time there are nineteen large battleships and battle cruisers under contract for propulsion by electric motors, ten of these being built by the General Electric Company and nine by the Westinghouse. Only one of these has been in extended service as yet, namely, the *New Mexico* with General Electric equipment, this being the first battleship contracted for. A second battle ship, the *Tennessee,* with Westinghouse equipment, has only recently gone into service. The equipment of these battleships in general, may be of interest as showing special features of speed control.

In this battleship drives the main propulsion motors form the only load for the generators. In consequence, the frequency can be fixed by design conditions, such as the desired speed for the generators and propelling motors and this frequency can be varied up and down over a wide range by simply varying the speeds of the driving turbines. Thus speed control is primarily by means of primary frequency, this being one of the few instances where this is practicable.

As the desired steam economies can not be obtained at the lowest required speed with this arrangement, a change in speed by means of pole changing, or its equivalent, in the motors themselves is obtained. For example: The motors on the *New Mexico* and the *Tennessee,* and a number of other battleships, are designed for twenty-four and thirty-six poles. In the battle cruisers, however, a different combination is used as will be mentioned later.

In ship propulsion by electric motors such as the above, there are several conditions which are very favorable to the electrical equipment, and which make the whole operation relatively simple and easy compared with other kinds of motor operation. In the first place, the motor is not tied rigidly to its load, as is the case, for instance, in locomotive work. In other words, the motor can start and come up to speed long before the ship has reached its full speed. On this account the secondary losses, rheostatic or otherwise, can be made very low, for the motors come up to speed in a very short time, while the boat may take many minutes to obtain full speed. If it were not for this feature, the rheostatic loss in starting and accelerating would be enormous, unless all such starting was done by means of speed adjustment of the turbine. As it now stands the propeller acts as a slipping clutch which gradually pulls the motor up to full speed without undue load on the motors themselves and with principal expenditures of power at the propellers themselves, which produces no harmful heating.

In the second place, the switching of the motors can be done without power. In other words, the excitation can be cut off from the generator when it is desired to switch the circuits, such as for pole changing or for reversing, for it is not necessary to maintain the driving torque at all times, as is the requirement in locomotive work. When drawing a locomotive up a grade, for instance, the tractive effort must be maintained during the operation of switching and this is one of the features which makes the problem difficult. In ship propulsion, on the other hand, this condition is absent or is of minor importance.

A third favorable condition in the ship propulsion problem is that there is no need for parallel operation of the generators.

In the *New Mexico* and the *Tennessee,* there are two generating units and four motors. For the higher speeds two motors are operated from each generator and, for lower speeds, four motors are operated from one generator. In the larger units, such as the battle cruisers, there are four generators and four pairs of propeller motors. At the highest speed there is one pair of motors on each generator. At intermediate speeds there are two pairs of motors on each of two generators, while at the low speeds there are four pairs of motors on one generator, but at no time is there any occasion for paralleling any of the generators. This simplifies the whole proposition materially.

On account of the huge capacities of the propelling equipments, not only is alternating current required but relatively high voltages. On the *New Mexico,* the *Tennessee,* and vessels of the same class, there are four main motors of about 7000 h. p. each, operated from two generators of suitable capacity. The size of these equipments necessitates a maximum operating voltage of about 3500. This voltage, of course, decreases with reduction of frequency in speed control.

In the battle cruisers, however, where there are four pairs of motors, each pair consisting of two 23,000 h. p. motors on one propeller shaft, the power of the motor is such that a maximum operating voltage of about 5500 is needed. Considering the possibilities of salt spray, etc. some very difficult problems are involved in the use of such voltages on sea-going vessels. On the battle cruisers a two-to-one combination of poles is desired instead of three-to-two on the smaller vessels. In consequence, here either pole changing or simple cascade arrangement of the motors is permissible.

On the speed control of the motors themselves, during starting, two radically different arrangements have been put out by the General Electric and Westinghouse companies. In the *New Mexico,* equipped by the General Electric Company, the two-phase motors are of the double cage secondary type, that is, the secondaries of the motors are equipped with two cage windings, the outer one, that is the one next the air gap, being of relatively high resistance for starting and accelerating and the inner one being of relatively low

resistance. Between these two windings is a sort of magnetic bridge for introducing a certain amount of reactance for the bottom winding. During starting and acceleration, the high-resistance winding furnishes a considerable part of the torque, whereas at full speed the low-resistance winding becomes effective. These two windings are proportioned to give the required torque results with both the 24 and 36 poles. Many problems of expansion, etc. came up in the development of this cage winding and, in fact, the end rings of the secondary contain what might be called "expansion joints."

In the contract for the *Tennessee*, which came later than the *New Mexico*, the Westinghouse company designed their motors for three-phase current, using two primary windings, one for 24 poles and the other for 36. The secondary winding is of the wound type and is connected to the collector rings in order that a starting resistance can be inserted. Certain cross connections on this 24-pole winding automatically act as short circuits when the primary is thrown to 36 poles, so that the secondary automatically becomes short-circuited under this condition. The rheostat is, therefore, inserted only for control on the 24-pole combination, the 36-pole being simply a running speed.

In later equipments of the *Tennessee* and *New Mexico* types of ships, the General Electric Company arrangement is somewhat different from the above, according to the information which the writer has received. Here there are apparently two windings on the secondary, one being a high-resistance winding equivalent to the cage type, while there is a 24-pole winding of the distributed type, which is inoperative on 36 poles, but which is short-circuited on 24 poles. The high-resistance cage winding is in circuit on both 36 and 24 poles.

While this arrangement, on the face of it, does not look as simple as the double cage of the *New Mexico*, yet it is intended to give better speed-torque and power factor characteristics.

On the battle cruisers the writer does not know what motor combinations are used by the General Electric Company, but in the Westinghouse, a special cascade arrangement is used to give half speed and lower. As the motors were laid out with wound secondaries, this cascade arrangement involved little or no additional complication for cascade operation.

In the super-dreadnoughts, which were contracted for after the battleships and battle cruisers, four motors of about 15,000 h. p. each are required with two generators of necessary capacity. The general arrangement is, therefore, quite similar to the battleships, except that the power requirements are practically double. In the Westinghouse equipment, the motors are for 24 and 36 poles, each motor containing two primary and two secondary windings, each secondary winding being suitable for starting on resistance.

It may thus be seen that this electric propulsion of large ships is not a radical undertaking. The motors are huge in capacity, but their speeds are such that from the mechanical standpoint they are not nearly as large as some of the steel mill motors which have been in operation for many years. One of the principal problems has been in the ventilation, for the equipment has to be installed in confined spaces and, therefore, artificial cooling has been resorted to in all cases. In fact, this has been possibly the most difficult problem in the whole design of these huge equipments.

This brings the induction motor up to the present. Its history has been a most interesting one to those who are at all familiar with it. To a certain extent this type of apparatus stands apart, in that its development has been due, almost entirely, to the analytical engineer. It is almost impossible to conceive that the induction motor could have been developed to its present high stage by ordinary "cut and try," methods. Some good motors might have been obtained in that way, but they would have been accidents of design, instead of the positive results of analysis, as the art now stands.

New applications are continually leading to new developments which are worked out by the analytical designer with an assurance of success not exceeded in any other branch of the electrical art. And the result of all the elaborate theory and complicated analysis and calculation is a practical machine of almost unbelievable simplicity and reliability;—a standing refutation of the too common idea that complexity in theory leads to complexity in results.

AUSTRALIAN STEAM-ELECTRIC PLANT TO USE 50-CENT COAL

Construction is to be started April 1 on a 125,000,000 kw. steam-electric plant, 112 mi. from Melbourne, Australia, according to announcement from Australian government offices. This is a governmental undertaking, to be carried out by the Victoria Electricity Commission, which proposes to develop extensive coal deposits at the plant sites, use the coal for generating electrical energy and transmit the power electrically to Melbourne and other industrial centers. Included in the project for which immediate construction is planned are a total of 1800 mi. of high-tension transmission line and three terminal substations. The trunk line voltage will be 132,000.

The coal deposits are said to be very extensive, . . . The coal can be delivered to the power house for about 50 cents per ton the report states. Condensing water is supplied by a river alongside the power house. . . . . .—*Engineering News-Record.*

Some Phases of Railroad Telegraph and Telephone Engineering

BY STANLEY RHOADS

Telegraph & Telephone Engineer, New York Central Lines

Statement of size of N. Y. C. Lines telegraph and telephone plant and variety of engineering problems involved. Telephones used almost exclusively for train dispatching, not so general for message work, but growing. Automatic telephones used. Extensive local and long distance lines and switchboards. Telegraph system reaches all stations. Pole line is basis of plant, increasing in strength to meet safely the loads to which subjected. Railroad employs wire chiefs.

Problems include electric protection, inductive interference, electrolysis, transmission, traffic, necessitating continual experiment and investigation. Telegraph answer-back used with selectors. Phantom telephone circuits used. Single wires for railroad telegraph obsolete; all wires used in simultaneous telegraphy and telephony. Extra high impedance telephones used for train dispatching. Iron wire joints welded. Battery consumption data; unit type switchboards designed, supplant dry battery for main selector ringing battery; chemical rectifier also used. Oscillograms of single-line telegraph current waves, when line insulation varies. Railroad long-distance lines can be loaded.

Telephone selector current waves given. Gill local bell selectors used with repeat coil signaling to obtain low-resistance simplex. Duplex telegraph used on about 10,000 miles of circuit on N. Y. C. Lines. Polar duplex is approximate three-wire circuit. Self-balancing duplex designed, especially adaptable at unattended repeater stations; oscillograms illustrating results in better balance of duplexes. No. 5-U retard coil of standard bridging duplexes and quads is auto-transformer as well as retard coil; is useful as retard, detrimental otherwise. Polar relay armature of differential duplex and quadruplex has more force than in bridging. Differentially connected relays are transformers to some degree. Inductive effects of differential sets. Standard quadruplex, common side, is too sluggish for hand-operated sending machines. Defects of quadruplex discussed. Limiting practicable lengths stated for various kinds of wire for telegraph and telephone circuits.

THE railroad telegraph and telephone department entered a new era when telephone train dispatching was adopted 13 years ago. In the last five years electrical engineers have been employed in this department in increasing numbers, and the development has become more rapid. Previously the telegraph and telephone departments of the railroads were content to depend on outside interests for ideas, equipment, methods of operation and development, and as a result the development was slow. The staff of one railroad telegraph department, with engineers continuously employed, has procured considerable advancement in the railroad telegraph and telephone plant in a space of four years, perhaps as much as was accomplished by all railroad telegraph and telephone departments in the four years previous to the period mentioned. This is attributed to the intensive application of electrical engineers to practical problems and obvious requirements of railroad service.

A difficulty confronting the engineer in the investigation of a problem, is to learn the state of the art in relation to the particular problem in hand. It is somewhat with the idea of presenting some data on the state of the art, as applied to railroad telegraph and telephone systems, that data and results of investigations are given here. It is hoped that any incomplete investigations can be continued by the engineers of the New York Central Lines and others; that any false conclusions can be pointed out, and that the data here presented may suggest investigations along other similar lines and on related problems.

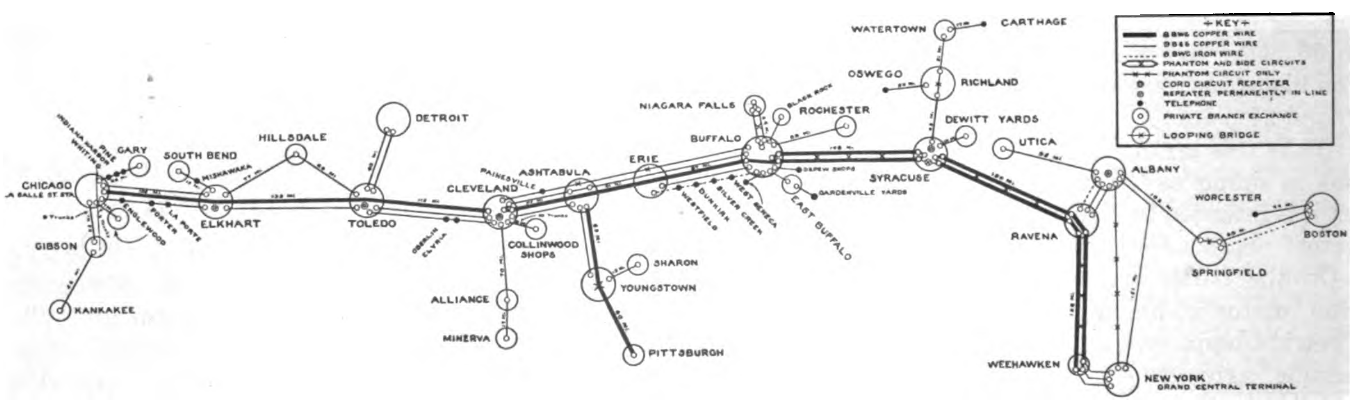

FIG. 1—NEW YORK CENTRAL LONG-DISTANCE TELEPHONE LINES

In order to interest others than railroad engineers in these problems, it can be said that the railroad telegraph and telephone engineer, particularly of the

Presented at the 9th Midwinter Convention of the A. I. E. E., February 16-18, 1921.

larger railroads, has problems of a variety that includes a little of about everything confronting the plant and traffic engineers of the large telephone and telegraph companies that have nation-wide service. The extent and distribution of the plant are the chief differences. This variety gives absorbing interest to the work. As the staff of the telegraph department is small, its engineers are obliged to handle any problem that arises as best they can.

New York Central Lines Telegraph and Telephone Plant

The plant under the supervision of the New York Central Lines Telegraph Department comprises 6 per cent of the total Western Union pole line and 12 per cent of the wire, and includes 12,000 miles of pole line with 80,000 miles of copper

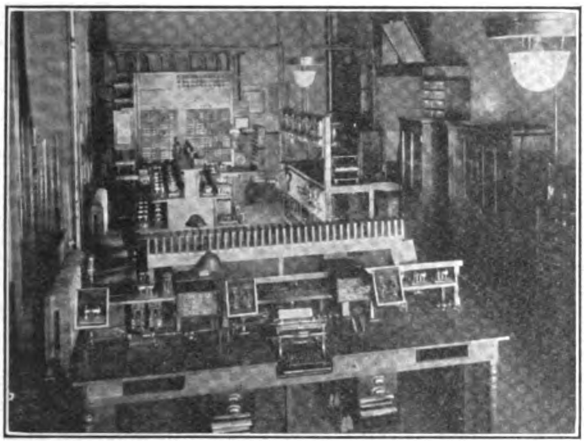

Fig. 2—C. C. C. & St. L. Ry., St. Louis Div. Headquarters Relay Telegraph Office

wire, of which 40,000 are used by the railroad; 76,000 miles of iron wire, of which 25,000 are used by the railroad on 12,000 miles of rail line. This includes a New York-Chicago long-distance telephone line, shown in Fig. 1, which has telephone repeaters, composite equipment, phantom circuits, and loaded cable. Practically all other important points from New York and Boston, to St. Louis and Chicago are connected in the network of service. Vacuum-tube telephone repeaters are installed at Albany, Syracuse, Cleveland, Toledo and Elkart, with one or two additional stations soon to be installed. These lines connect railroad telephone exchanges in some cases larger than required to serve the public in small cities. The total number of long distance calls handled is about 5000 calls per day. New York and Chicago have 12 position boards, and others are in proportion to the amount of business done. The New York Central Lines have about 5500 telephones on P. B. X. boards and 4000 direct exchange lines. The number of local calls is enormous, but is not kept count of ordinarily. City calls are counted by the telephone companies in order to make the billing where this is on measured rates. These boards are operated by the railroad, but furnished and generally maintained by the Bell telephone companies. The railroad offices in large cities have numerous one-position sub-boards in various departments.

The railroad telegraph service with its network of 40,000 miles of copper and 25,000 miles of iron wire in its own service, reaches 3700 offices. The centers of operation at headquarters of the general staff of the railroads have large offices called general telegraph offices. The division headquarters telegraph offices are called relay offices. Such an office at Mattoon, Ill., is shown in Fig. 2. This office serves two telephone dispatching circuits, four telephone message circuits, two phantoms, four yard lines, two Western Union way Morse wires, four railroad single-line Morse wires, two of which are connected through repeaters, three duplex Morse wires, two of which are connected through repeaters. New York has a force of 20 telegraph operators, Indianapolis 18, Detroit 16, Chicago 14, Cleveland 13, and other cities in proportion.

The telegraph service is more extensive than the telephone long-distance system, because it must reach every station and office on the system; whereas, the telephone long-distance service is limited to the officers and employes who have Bell telephones that connect to the railroad telephone exchanges, and the way stations in general do not have access to the long-distance lines.

Direct through service is maintained between the important centers and in nearly every case between adjacent division terminals. For example, New York has a direct Cincinnati wire, also one each to Chicago, Detroit, Cleveland, Buffalo, Rochester, Syracuse, Watertown, Corning, Albany and Boston. Single Morse has the greater total mileage, duplex Morse next, but only a small amount of quadruplex is used because of its limitations.

The thirty New York Central Lines relay telegraph offices handle about 55,000 railroad telegraph messages per day. No attempt is made to count the messages handled by one way station with another, unless they are relayed or sent or received by the general or relay telegraph offices. The way-station operators receive and transmit Western Union commercial messages in addition to the railroad messages.

Some printing telegraph service is employed between relay offices. At present, this is limited to New York to Albany and Cleveland to Toledo. The operation is duplex, single channel, Morkrum type in both cases. In the hand operation, single, duplex and quadruplex service is employed.

The telephone is used almost exclusively for train dispatching on the New York Central Lines, consisting of 108 circuits, with 3020 selectors on 10,271 miles of railroad. It is also being extended for way-station message service on dispatching divisions, but is at present in use on 48 circuits with 1464 selectors, less

than half the total New York Central Lines mileage. When business returns to normal it is expected that this service will rapidly extend until the railroad is on a complete telephone basis. Several different types of selectors and telephones are in use for these dispatching and message circuits.

Two railroad automatic telephone systems are in service, one at Detroit and one at New York in the electric division, neither of which is connected to the Bell telephone system. The New York installation comprises five interconnected exchanges, with 600 stations. The system centers in Grand Central Terminal but has exchanges connected by trunks, at West 72nd St., Mott Haven, Harmon, and White Plains. The latter two are each about thirty miles from New York. An immense volume of traffic is handled on this system. The Grand Central Terminal board handles about 2000 local calls per day, 500 incoming trunk calls, and 700 outgoing to and through Mott Haven. The high hourly load is between 3 and 4 p. m., during which period about 600 local calls are handled daily.

The privately owned telephone cable plant is gradually extending. It now extends nearly twenty miles out of New York on both the Hudson and Harlem Divisions, and will extend eventually thirty miles on each. In other cities the private cable plant is growing in proportion. In the New York territory loud-speaking telephones are used for train dispatching, also for train announcing between interlocking towers in the vicinity of Grand Central Terminal. "A" tower on the upper level of Grand Central Terminal has in use almost all practicable methods of wire communication, including, Bell and automatic telephones, telautograph, loud speaking telephone circuits, lamp signal annunciators, bell annunciators, private line telephones, and selector telephone train dispatching and message lines. Private line telephone connection is provided between ticket sellers at the stations in the larger cities and the Pullman reservation departments in the same cities, over which reservations are handled. The telephone system is specially designed for this service. Some lines are provided from the reservation desk to the regular telephone switchboard. Special boards or tables are provided for passenger train information at the larger terminals, connecting with the regular telephone switchboard, as well as direct to the Bell city exchange.

The construction and maintenance of the pole lines, except some private line and cable, is under the supervision of the telegraph department in accordance with the contract with the Western Union Telegraph Co. and under the specifications of the latter after approval by the railroad. The installation and maintenance of the inside telephone plant is under the supervision of the telegraph department and is performed under the railroad's own plans and specifications. The telephone companies install and maintain the rented telephones and switchboards. The inside telegraph plant is installed and maintained by the railroad chiefly under Western Union Telegraph Company specifications under the contract between the two companies.

The pole line is the backbone of the telegraph and telephone plant. Railroad pole line construction in the past has been very largely based on the average-strength plan, which for a given load of wires provides that the class of poles shall be the same regardless of the extent of the exposure to ice and wind. No estimate is available to indicate how much of the average-strength type of line is too weak, too strong or just strong enough. Lines that are stronger than necessary have cost the

Fig. 3a—Line Replaced Modern Pole Line

railroads more than was warranted for their construction, while those that are too weak will require large expenditures for maintenance, particularly after severe storms when stretches may be laid flat. Additional losses result from service interruption. Such interruptions not only consist of the loss of wire service, with the consequent train delays, but may result in a blockade when poles fall across main tracks, as has happened frequently.

In order to reduce the pole line damage and traffic interruptions to a minimum, railroad telegraph and telephone engineers have worked out an exact strength

Fig. 3b—Way-Station Installation

of line with an allowable factor of safety based on wind and ice data for the localities in which the lines are located or are to be built for use in construction and reconstruction work. Wind and ice data may be determined readily in any locality so that railroads can construct lines on an exact strength of line basis with a proper factor of safety which should result in economy.

The reconstruction of pole lines along the New York Central Railroad is now being handled on this basis.

The desirable line consists of a cable and not more than two arms of open wires. Fig. 3A shows this type of line at Cleveland, Ohio, built on the factor of safety or exact strength design, also the old type of line which it replaced.

The type of telephone and telegraph installation now approved for way offices includes a metal box unit containing electrical protection, cross connections and terminal blocks; metal box units with porcelain panels and very substantial jacks, for patching and testing circuits; factory made cables; caustic soda primary battery common to transmitter and selector bells; and conveniently located table apparatus Such an office is shown in the two views of Fig. 3B, in which the door of the metal box containing the electrical protection, is open.

The wire testing is performed by an organization of railroad wire chiefs, each testing office having about one operating division to supervise, which is, roughly, one hundred and fifty miles of railroad. Many of these points have three "tricks," that is, a wire chief is on duty at all times. Others have but two men per day and some have but one. Wheatstone bridge testing methods are used; also the voltmeter and milli-ammeter. The station linemen maintain both pole lines and station equipment on most of the New York Central Lines.

Problems arising from the construction, maintenance and operation of the railroad telegraph and telephone plant include electrical protection, inductive interference, electrolysis and telephone and telegraph transmission and traffic. Investigations and experimental work are continually necessary in various phases of the engineering. The oscillograph of the Electrical Engineering School of Purdue University has been available for about five years in these investigations, the major part of which has been made on actual working lines.

Telegraph Traffic Problems

Telegraph censors are employed on two of the New York Central Lines for the purpose of reducing unnecessary telegraphing and telephoning and reducing the number of words in necessary telegrams. A large part of the duty is educational in giving other departments an idea of the proper use of the telegraph. The results accomplished are more than enough to justify the expense. One failing that has been reduced is the tendency to let messages stay in the originating office until closing time at night, sending them to the telegraph office at the same time the train mail is sent to the mail-room. This overloaded the telegraph office at a time when outlying offices were closing for the day and many such late messages would be held over until the next day. The telephone traffic is more difficult to censor, as no record of subjects of conversation is made—an unnecessary message must be caught in the act of transmission. Rules are in effect which prevent unlimited use of the long-distance telephone service, calls for the higher officials being given preference.

No charge is made against any department for the railroad telegraphing done by it and no records are kept for that purpose, but a numbering scheme is employed to give a check on the volume of business and the cost of handling it. The railroads have quite generally adopted a numbering scheme for telegraph messages based upon counting one number for each message of three lines or less, an additional number for each additional three lines, and an additional number for each additional address if addressed to more than one person. Ten words are counted as a line; extra numbers are allowed for reports which are termed "make ups." Only the larger offices keep such a record; that is, way stations do not. The division relay offices make a daily and monthly record of messages handled, which, on the New York Central Lines, are compiled and presented graphically as shown in Fig. 4, which shows total messages handled per month, the cost per message and the average number handled per man per hour.

An analysis of the messages handled on three different circuits is interesting and is tabulated below:

TABLE I

	New York-Albany Morkrum printer	New York-Chicago operator	Big Four Route operator
a. Number messages reported...........	441	391	348
b. Correct number messages..........	367	387	357
(Difference between a and b is operators' error in recording numbers handled.)			
c. Actual number pieces paper.............	259	245	261
d. Actual minutes required	165	379	328
e. Number per minute..	$\frac{367}{165} = 2.22$	$\frac{387}{379} = 1.02$	$\frac{357}{328} = 1.09$
f. No. per man per hour	66.72	61.25	65.25
g. Possible number per 8 hours...........	1065.6	490	522

The above mentioned printer circuit is duplexed and the total number of messages possible in eight hours includes the total sent in both directions. One man only, at each end, is needed and each can send one-half the total, or 533 messages, in eight hours. On the ordinary Morse circuit it requires two men, one sending and one receiving, to handle this number of messages.

The printer receives with scant attention, and the possible 1065.6 would be reduced if the circuit were in trouble or failed to transmit perfectly. The evidence is plain that the printer will handle about double the load with one man at each end, that a Morse wire will

handle. Including all items of cost, operators will handle the business cheaper than the printer up to a total of about 400 numbers, including both sent and received, but this varies with rates paid operators, etc.

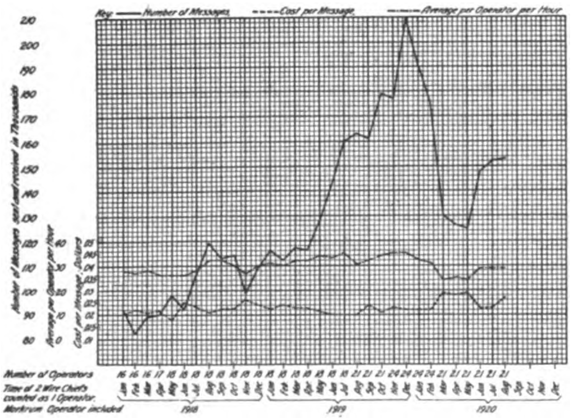

FIG. 4—TELEGRAPH TRAFFIC RECORD, "Q" TELEGRAPH OFFICE N. Y. C. R. R., NEW YORK

The averages of Table II indicate that nearly 35 per cent of railroad messages are one line or less; 35 per cent are one to two lines; perhaps, 15 per cent are two

TABLE II

	N. Y.-Albany	% of 259	N. Y.-Chgo.	% of 245	Big 4	% of 261
Actual number pieces paper	259		245		261	
1 line or less	88	34.0	93	38.0	68	25.0
1 line to 2 lines	98	38.0	79	32.2	91	35.5
2 lines to 3 lines	20	8.0	35	14.3	55	21.1
3 lines to 6 lines	45	17.0	31	12.7	38	14.4
Over 6 lines	8	3.0	7	2.8	9	3.5
Extra count for excess over 3 lines	66	....	49	....	79	....
Extra count for make-ups and joints	42	....	93	....	17	....
Total numbers	367	....	387	....	357	....

to three lines; 10 per cent are three to six lines and not more than 5 per cent are over six lines. This indicates that 85 per cent of the messages are less than

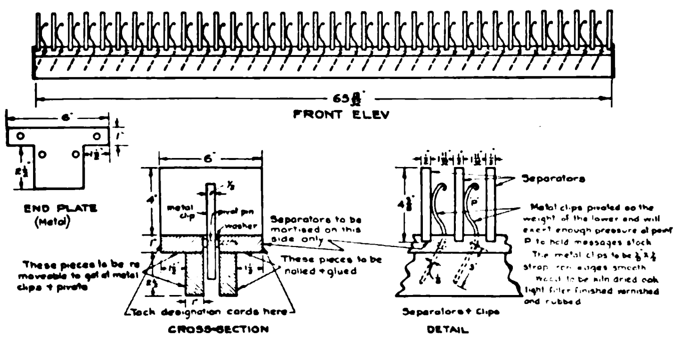

FIG. 5—OPERATORS' TABLE RACK FOR HANDLING MESSAGES TO BE TRANSMITTED

three lines and small error would result if only one number were counted per message regardless of the number of lines.

A mechanical device, which the railroad designed for assisting in prompt handling of outbound messages, is shown in Fig. 5. It can also be seen on the telegraph operating table in Fig. 2. It is a gravity clip

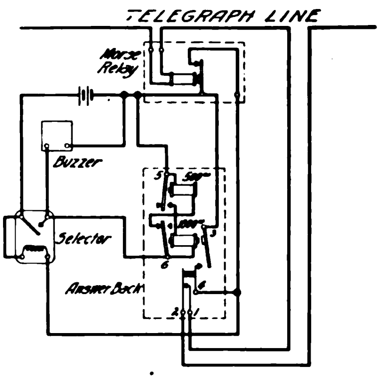

FIG. 6—TELEGRAPH SELECTOR ANSWER-BACK, TYPE A, FOR SINGLE MORSE CIRCUITS

message holder, from which messages can be reached from both sides of a quartette operating table. Each division of it has a designation card for some outlying office.

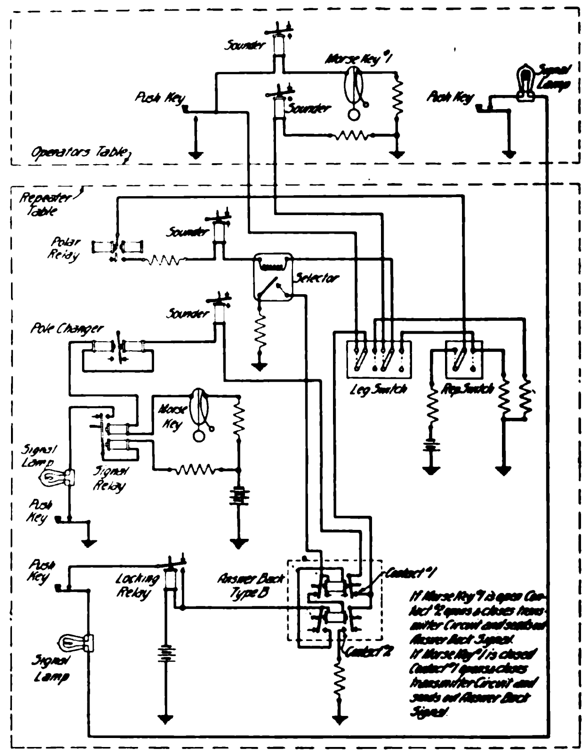

FIG. 7—TELEGRAPH SELECTOR ANSWER-BACK, TYPE B, FOR DUPLEX AND QUAD USE

TELEGRAPH SELECTOR AND ANSWER-BACK

The telegraph selector has been a growing factor in railroad telegraph traffic in recent years, until it is now considered an essential part of a modern relay office and is growing in favor for way-station use. It is quite generally used in conjunction with the lamp

signal concentration unit operating table for signaling offices. When the selector is operated by the distant station sending the proper code of impulses on the wire, it lights a lamp in the concentration unit. In concentration units many Morse wires are available to one or more positions of an operating table. Means of notifying the calling office that the selector had functioned was lacking until the telegraph selector answer-back of Fig. 6 was produced by the railroad. The fundamental idea is to cause the telegraph circuit to open and close at a speed corresponding to rapid dots,

Form TD. 62 O P 1m 8 15 18 5952

TELEGRAPH SELECTOR CALL CARD

To Operators at__________________

This instructs how to call

____________________ Office

on wire number__________________

Make dots as long as Morse letter L.

Make dashes longer than Morse numeral O.

The selector {is / is not} equipped with Answer Back, which will buzz the line while bell rings

Do not waste time making Morse call, use the selector. A sounder {is / is not} in circuit.

"HW" CINCINNATI, OHIO

CLEARING IMPULSES — — — — ———

1 ———

2 — ———

3 — — ———

4 — — — ———

1 ——————

BELL RINGS DURING THIS IMPULSE

Notify Wire Chief if selector fails.

Date__________191__

____

Supt. Telegraph

FIG. 8—TELEGRAPH SELECTOR CALL CARD

which begin when the selector contact closes and continue until some one along the line opens the circuit; that is, the selector answer-back is under the control of any station. The two coils of the answer-back operate alternately to produce the speed of vibration desired at line contacts 1 and 2. Contacts 3 and 4 maintain the selector circuit closed while the Morse relay contact is released, which occurs when 1 and 2 open. The answer-back is also applied to duplexes as shown in Fig. 7 and will give a signal whether the key at the selector station is open or closed. The selector is operated in the local sounder circuit of the polar relay and the answer-back opens and closes the transmitter local sounder circuit to send the signals to the calling station. This device on either single line or duplex gives operators considerable satisfaction in knowing they waste no time in calling, and it promotes efficiency of service. The card sent out to notify stations of the combination and method of making it is shown in Fig. 8. The selector combination is placed on this with a rubber stamp, because, generally, only two or three score are needed and individual printing cannot be justified. It is found that the signal is easier to make with the combination printed in a vertical column, with one group of impulses below the other, than with the whole combination strung out in one line. At smaller offices where more than one selector is used but no lamp signal concentration unit is provided, a special design of visual signal box based on the railroad's design is used.

One of the best examples of the value of the telegraph selector is on the New York Central Lines on a telegraph train report wire extending from New York to Chicago and known as the "GX" wire. The wire is used for reporting the time that through passenger trains pass the several important points, to the recorder's office at New York. This office has a keyboard with Gill selector keys about the same as on a telephone train dispatching circuit. The selectors are distributed from New York to Chicago. The circuit has six sets of telegraph repeaters, which gave trouble in adjustment until the Chicago end was equipped with a selector and answer-back. This gives the recording office operator instant check on the repeater adjustment and continuity of the circuit. If he calls Chicago and gets the answer-back, it is evidence that the repeaters are fairly well lined up and that the circuit is unbroken.

RAILROAD SIMULTANEOUS TELEPHONY AND TELEGRAPHY

The railroad makes use of simultaneous telephony and telegraphy on practically all its wires, including station-to-station block telephone circuits, train dispatching circuits, message telephone circuits and long-distance lines. The station-to-station block telephone simplex is illustrated in Fig. 9 which indicates "single" Morse on the simplex, but this type of circuit is very successfully duplexed and has been quadruplexed with good results in some cases. This block telephone circuit is very seldom used in a phantom, because there is but one such circuit on any one pole line and this is looped in and out of every office, and further, being iron wire in nearly all cases, it would not give transmission up to the required standard, for the distances phantoms are required to cover in railroad service.

Dispatching and message telephone circuits are like Fig. 10 in general, if direct-current impulse selectors are used. This figure indicates the added resistance that is necessary with the simplex coils to prevent the coils short-circuiting the direct-current impulses which operate the telephone selectors. A phantom composited is shown such as are made up from dispatchers and message circuits on one railroad di-

vision. This figure without the composite equipment and without the condensers around the added resistance in the simplex coil bridges, illustrates an ordinary

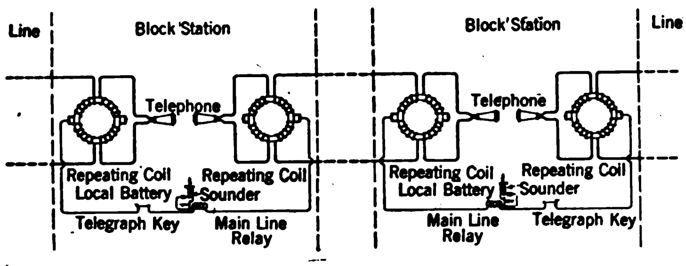

FIG. 9—STATION-TO-STATION BLOCK TELEPHONE SIMPLEX

high-resistance simplex. Straight Morse is shown but these are often duplexed in the service of the larger railroads to gét better service in weather that would reduce the margin of a single Morse circuit to an unsatisfactory degree. The dispatchers and message telephone circuits on each division with few exceptions are paired into a phantom by proper transpositions, and composited. In recent high-resistance phantom installations two separate repeating coils are used on each circuit at each end, one for the telephone tap and the other for the telegraph. The No. 5-AA retardation coil combines the two separate Morse leg coils in one unit, likewise combines the shunt retardation coils in one unit, each unit having two separate and distinct magnetic circuits with but one cover and base. If alternating-current selectors, which are alternate positive and negative impulse selectors, are used, a repeating coil scheme of sending the impulses can be employed, in which case the same coil is used for the Morse and phantom connection to the physical pairs as indicated in Fig. 11. This gives a low-resistance simplex, generally 1000 ohms or more below the ordinary "high-resistance" simplex of Fig. 10, assuming 150-mile lines of No. 9 A. W. G. copper wire. The composite ringer is used for signaling between the terminals on phantom circuits which are composited.

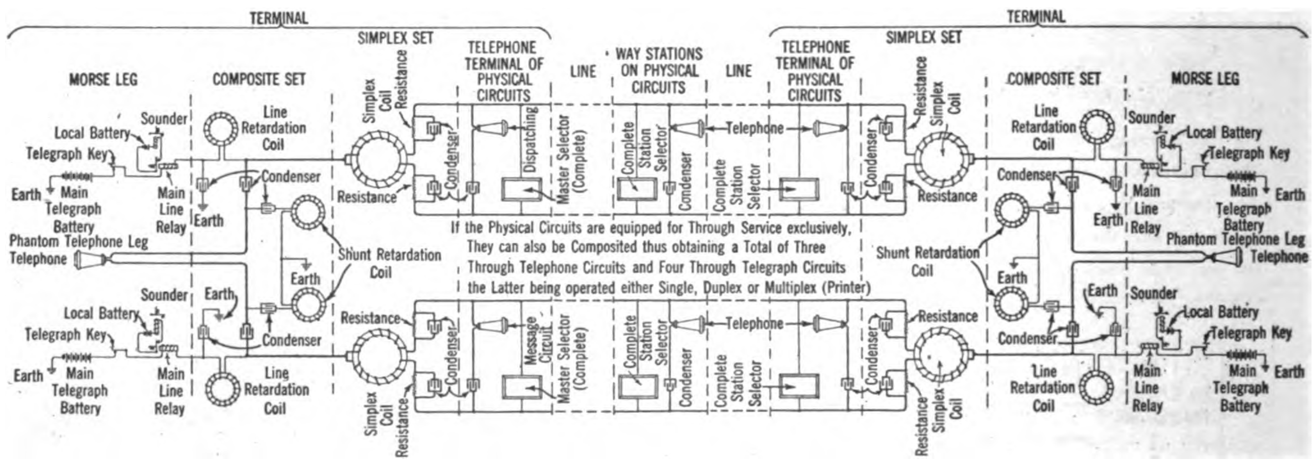

FIG. 10—HIGH-RESISTANCE SIMPLEXES WITH COMPOSITED PHANTOM

Long-distance telephone lines are simplexed if the transmission losses incident to the use of composite apparatus are prohibitive; also if there are any intermediate telephones, or if there is no need of additional telegraph sérvice. The railroads generally have no spare telegraph facilities and can use all they can get. The simplex can be single, duplex, or quadruplex. Two such circuits can be made up into a phantom without simplexing or compositing. This is frequently done in railroad service for trunk lines between outlying private branch exchanges and the main branch exchange. In some cases repeating coils are inserted in the phantom drop circuit and a Morse circuit connected to the middle of the line side, thus making a four-wire simplex telegraph circuit. This, in some cases, is done instead of compositing the phantom which would give two Morse circuits, in order to obviate composite ringers; in other cases it is to get more copper in the Morse circuit, for example when No. 19 A. W. G. cable conductors are used, in trunks between offices in metropolitan districts.

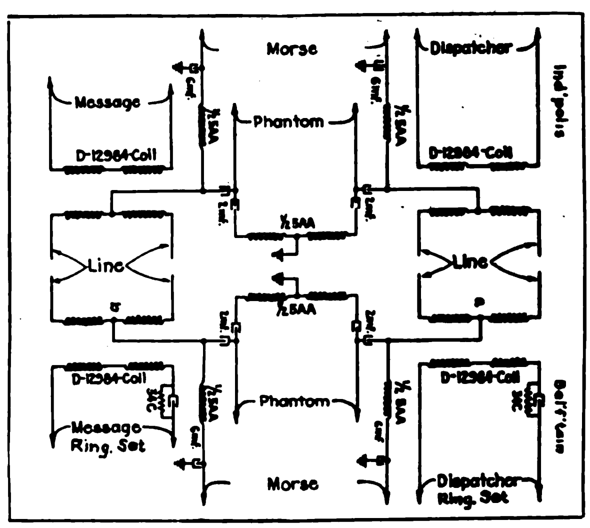

FIG. 11—LOW-RESISTANCE SIMPLEXES WITH COMPOSITED PHANTOM

If no intermediate stations are required on a long-distance line, and the transmission volume is ample,

the two wires of the pair are composited with which composite ringers are used and with Morse legs carrying either single or duplex telegraph. Two of these long-distance composited pairs can be phantomed if properly transposed.

Single wires for telegraph purposes only, are almost a thing of the past for railroad service along some of the large railroads. This is because of the economy in using all available wires for simultaneous telegraphy and telephony. Before the advent of telephone train dispatching there were very few long-distance telephone circuits. The New York-Chicago, New York Central No. 8 B. W. G. copper pair which was strung in 1904 was a notable exception. The division service on many trunk lines consisted of one iron Morse train wire, one iron message wire, and very rarely, an iron wire for station-to-station grounded telegraph block circuit. When a telephone dispatching copper pair was strung, resulted in complaints, some officials thinking the "connection was poor," when they were talking on the iron circuit. It was found that no circuit diagram was available for a combination of a composited pair and a simplexed pair for a phantom, and it was necessary to develop one by experiment. The result is shown in Fig. 12, which indicates that each side of the dispatching telephone line is treated as a composited wire; that is, there is one-half of a No. 5-A A retard coil in each wire. This was found necessary to give a quiet phantom terminal set. This type of circuit gave almost as good a phantom circuit as Fig. 10. The two retard coils in each end of the simplex did not reduce the speed of Morse service, because but half the telegraph current went through each. The capacity to ground on each side of the set at the retard coils was made three microfarads on the simplex and six microfarads on the composite. The equipment

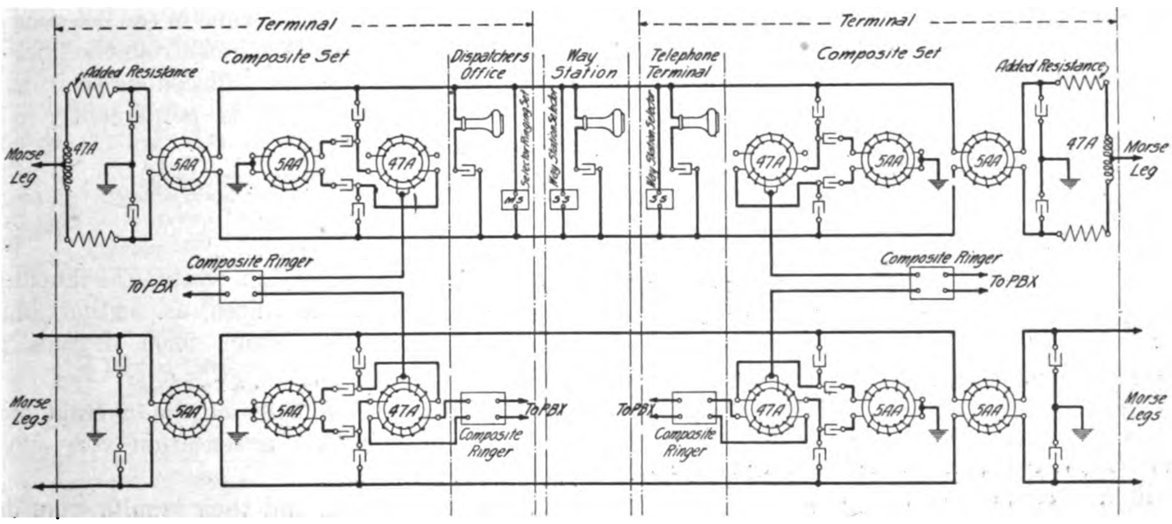

FIG. 12—TWO METALLIC TELEPHONE LINES WITH THROUGH PHANTOM, ONE PHYSICAL SIMPLEX, AND EQUIPPED FOR WAY-STATION TELEPHONE SERVICE, OTHER COMPOSITED THROUGH TELEPHONE LINE

the old train wire and message wire were generally paired and made into a station-to-station block telephone circuit and simplexed for the way-station Morse message wire. The addition of a message telephone copper pair at a later date completed the division service and provided a long-distance phantom circuit which was generally as much needed as the way-station message telephone pair. This leaves many divisions with no single wire—nothing but pairs, simplexed or composited for telegraph.

A phantom made up of one composited pair and one dispatching circuit was developed by the railroad for a special situation between Indianapolis and Cincinnati, which points were connected for long-distance service by one No. 8 B. W. G. iron composited long-distance line and one No. 9 A. W. G. copper phantom, the latter consisting of the dispatching and message circuits. The phantom gave much better transmission, and because calls for the same party were first on the iron circuit and next on the copper, it on the office side of the No. 5-A A coils has no effect on the circuit as far as phantom noise is concerned, which permits of the three microfarads on one circuit and six microfarads on the other.

EXTRA HIGH IMPEDANCE TELEPHONES

In arranging for the simplex-composite phantom, it was necessary to use the iron wire circuit as a way-station message telephone circuit, and use the copper pair formerly in this way-station service, as the composited pair of the phantom. This would not have been possible but for a recent advance in telephone transmission which resulted from the use of extra high impedance telephones. The improvement in telephones was the result of experiments made necessary by the emergency use of a one-hundred-mile No. 8 B. W. G. iron wire circuit as a dispatching circuit, in order to divide two dispatching districts into three parts for handling unusually heavy freight traffic that existed just previous to the entrance of the United States into the war. No means of calling stations was

provided on this circuit, so that all stations continuously listened in. There were 30 of them, and the resultant "listening" losses were so great that stations at one end of the line could not hear those at the other end. This gave the clue to the cause of other transmission troubles, which were that at certain periods of the day, transmission on dispatching circuits was excellent and at other periods it was very poor. The evidence now is plain that in the evening hours, when

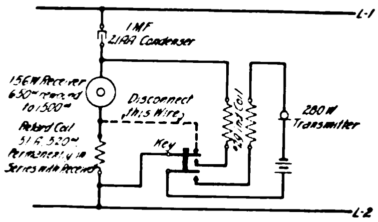

FIG. 13—295-AK AND 300-W SUBSETS CONVERTED TO EXTRA HIGH IMPEDANCE TELEPHONE BY USE OF 1500-OHM RECEIVER

the transmission was poor, many operators were listening in. At other times, particularly in the morning hours, transmission was good because the operators were busy with other duties and had the receivers on the hooks.

The outcome of the investigation was the use of 1500-ohm receivers with a retard coil permanently in series as shown in Fig. 13. It was found that with these sets, all stations on the hundred-mile iron wire circuit could listen in simultaneously without noticeable diminution of transmission. The results on dispatching copper circuits, especially the ones with a large number of stations, were likewise gratifying. Some of these dispatching circuits have 60 to 65 stations, whereas the average over the country is but thirty, and the telephones previously in use, with 650-ohm receivers, were designed for a maximum of about 15 receivers off the hook at once. The 1500-ohm receiver is equally effective on the Wray-Cummings "booster" telephone, which also has a retard coil permanently in series with the receiver. The Western Electric Company had developed an extra high impedance set with a repeating coil and 70-ohm receiver, which was about ready to put on the market and which was put out very shortly thereafter. This gives the benefit of high impedance when in the listening position and also insulates the telephone from the line. In this set the repeating coil is not disconnected from the line by the hook-switch but is permanently connected across the line.

(To be continued)

DETERMINATION OF THE STANDARD FOR "WHITE LIGHT"

The definition of "white light" naturally constitutes a very important part of the scientific foundation of colorimetry. If we consider incandescent light sources generally (including oil and gas flames; carbon and metallic filament electric lamps) we find that the light from sources at comparatively low temperatures evokes reddish or yellowish colors. As the temperature of the source increases, the color becomes paler and paler yellow and, at higher temperatures, approximates to "white." However, all artificial incandescent sources are decidedly yellow in comparison with sunlight, since it is not possible to operate an artificial source at a sufficiently high temperature to color-match sunlight. We are led to anticipate, however, that a source at a sufficiently high temperature would color-match sunlight, and further that sources of still higher temperatures would appear blue relative to the sun. The question arises as a matter of physiological optics, at what temperature would a source appear under standard conditions of observation neither blue nor yellow but white. The further question then arises relative to this standard, is the sun blue, yellow or white? Recent experiments made at the Bureau of Standards, Washington, D. C., answer these questions in so far as four observers are concerned. They are the first accurate experiments of this nature ever performed. The answers are:

1. Theoretical. The temperature which a hypothetical source would have in order that its light might evoke the sensation white (the hueless sensation of brilliance recognized as neither bluish nor yellowish) would be about 5200 degrees absolute Centigrade.

2. Practical. The light of the average noon sun at Washington evokes a sensation very closely approximating white.

These experiments and their results were described at a joint meeting of the American Physical Society and the Optics Society of America in Chicago, December 29, 1920. It is expected that they will be described in detail in a forthcoming publication of the Bureau of Standards and persons desiring further information should address such request to this Bureau, attention of Division 4, section 3.

TESTS OF AUTOMOTIVE FUELS

Tests are being carried out at the Bureau of Standards on special blended fuels at the request of other government departments. Conferences have been held with members of the Fuel Research Committee of the Society of Automotive Engineers and other organizations, including representatives of the government, looking toward the formation of a definite program for the investigation of various fuel problems of interest in connection with automotive engineering practise. During a recent visit of one of the members of the Bureau's staff to Europe a special study was made of fuel conditions abroad.

Developments in Conversion Apparatus for Edison Systems

BY T. F. BARTON and T. T. HAMBLETON
Both of the General Electric Co.

ELECTRICAL energy for Edison systems is most efficiently produced and distributed to substations in the form of alternating current. At the substation it is converted into direct current and distributed to a three-wire network at a suitable voltage.

Conversion apparatus for Edison systems has taken the form of motor-generator set, synchronous converter and dynarotor. The voltage-range requirement of this service caused the development of several schemes for effecting voltage range with a synchronous converter. The tap changing switch with the transformer, the induction regulator, the regulating pole construction, the synchronous booster and field control are the forms which have been or are in commercial use.

Edison systems operating at 25 cycles have used synchronous converters almost entirely. At 60 cycles the motor-generator set, both synchronous and induction has been used extensively on account of the questionable performance of the early 60-cycle converter.

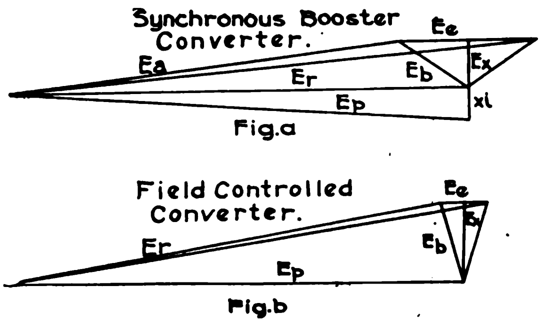

FIG. 1—VECTOR DIAGRAMS, SYNCHRONOUS BOOSTER AND FIELD-CONTROLLED CONVERTER

Conversion apparatus for Edison systems must provide sufficient voltage range to maintain constant voltage at the load centers. The range depends on the amount of copper in the feeders and network, location of substations and load density.

In order to present the facts which should be considered in selecting the more suitable type of conversion apparatus for a particular service, the characteristics of the synchronous converter and the modern motor-generator set will be discussed.

SYNCHRONOUS BOOSTER CONVERTER

The synchronous booster has superseded the induction regulator because of lower first cost, greater reliability, and simpler substation layout. Its characteristics will be considered in detail for comparison with other types.

Fig. 1*a* represents vectorially the relation of the voltages in the converter, booster and transformer at full load. For simplicity, the resistance drops have been omitted. Unity power factor is assumed at the collector rings. The following table specifies and gives the values of the voltages.

E_R	—Collector ring voltage	100
E_x	—Booster reactance voltage from load current	10
E_e	—Booster energy or field voltage	15
E_b	—Booster armature voltage	18
E_a	—Converter armature voltage	85 or 115
$x\,i$	—Reactance drop in transformer and leads.	7.5
E_p	—Primary voltage	100. +

The principal component of E_x, the reactance voltage of the booster, is generated by the armature conductors cutting a magnetic field set up by the armature reaction of the load current in the neutral space and adjacent pole tips. It is 65 to 70 per cent of the designed voltage of the average booster.

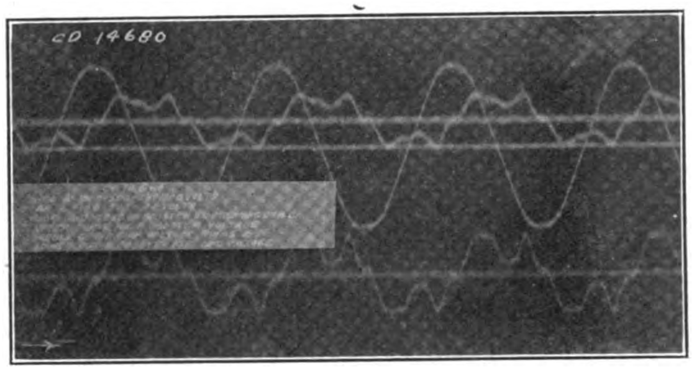

FIG. 2—OSCILLOGRAPH RECORD, 1000-KW., 25-CYCLE SYNCHRONOUS BOOSTER CONVERTER

Uper curve—Collector ring voltage
Middle curve—Booster armature voltage
Lower curve—Booster armature exploring coil voltage

Fig. 2 is an oscillograph record showing the voltage at the collector rings, voltage of booster armature and of an exploring coil in the booster armature. The latter indicates the field form of the flux set up by the armature reaction. Such a field form will cause high core loss and eddy current loss in the armature conductors. The eddy current loss is materially reduced by the use of stranded cable conductors in which the individual strands are adequately insulated.

The power factor at any point in the circuit can be determined from the relations shown in Fig. 1*a*. For unity at the collector rings the converter is furnishing

To be presented at the 368th Meeting of the A. I. E. E., New York, March 11, 1921.

10 per cent leading kv-a. (99.4 power factor). For unity at the primary terminals of the transformer, the converter armature must furnish leading kv-a. to the amount of 10 per cent for the booster reactance, 7½ per cent for the transformer and lead reactance, and 5 per cent transformer magnetizing current,—totaling 22½ per cent (97.5 power factor).

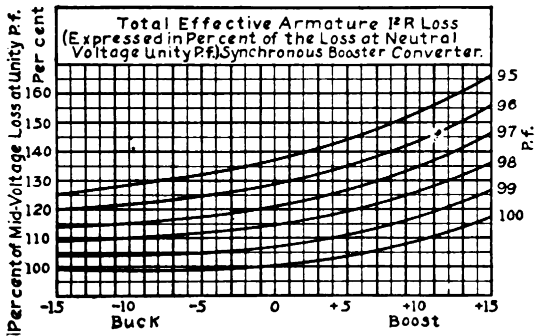

FIG. 3

The values here assigned to reactance and magnetizing current are a minimum for modern designs; therefore, combinations, especially at 60 cycles, will be found where the converter armature must operate as low as 95 per cent power factor leading to hold unity at the transformer primary.

Fig. 3 shows the effect of power factor and booster on the average $I^2 R$ loss of the armature conductors. Fig. 4 shows the effect on the $I^2 R$ loss in the armature conductors in the tap zone. The tap zone includes the armature conductors in which the greatest average $I^2 R$ loss occurs and is therefore the hottest spot in the converter armature. It is here taken as the tap slot and the adjacent slots on either side. The greatest loss occurs in the tap coil at unity power factor. The greatest average loss at any leading power factor takes place in the conductors in the slot next ahead of or in the direction of rotation from the tap slot. The converse is true for lagging power factor.

The $I^2 R$ loss in the tap zone of a converter increases at a much greater rate for a change in power factor than in any other type of alternating-current machine. It is, therefore, of the greatest importance that a converter be operated within the power factor limits for which it has been designed.

The transformer capacity is usually 5 to 10 per cent greater than the converter. The high-voltage winding is arranged with four 2½ per cent full-capacity taps below rated voltage. The low-voltage winding is provided with a 50 per cent tap for connecting to the neutral of the Edison system. Suitable taps and lead arrangement are provided in either winding if a-c. starting is required.

The reactance and exciting current are a minimum consistent with conservative transformer design. An upper limit of 7½ per cent for each is set for continuous rated machines. The rated secondary voltage should be as high as the range of the booster, together with the application requirements, permits, for such an arrangement gives the best efficiency, lowest heating and most stable operation.

In the simple converter there is a fixed relation between the direct and alternating currents. The resultant armature reaction under the commutating pole, therefore, varies directly with the load current and may be neutralized by a series winding. This relation exists also in the synchronous booster converter when the booster field is not excited. The series winding alone maintains commutation at the mid or neutral voltage.

When raising or lowering the voltage, the booster operates as an alternator or motor; the converter as converter and motor or as converter and d-c. generator. The armature reaction of the motor current in the converter armature magnetizes, and, of the generator current, demagnetizes the commutating pole. To maintain correct commutation, these effects must be neutralized. This is accomplished by a second winding on the commutating pole properly excited and controlled. This winding, in the case of a 15 per cent booster, is approximately 40 per cent of the series winding. Its control, therefore, must be accurate and reliable.

FIELD-CONTROLLED CONVERTER

The field-controlled converter was developed to meet the need of a limited voltage range machine.

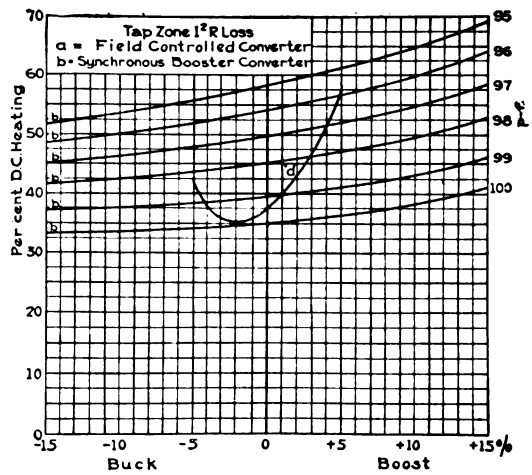

FIG. 4

The voltage range of certain buses in large substations is small although the range of substation voltage is large.

Fig. 1*b* represents vectorially the relation of the voltages in the converter, reactance and transformer at full load. The resistance drops are omitted as in Fig. 1*a*. Unity power factor is assumed at the transformer primary. The following table designates and gives the value of these voltages:

E_p	—primary voltage	100
E_x	—reactance drop from load current	17½
E_e	—energy voltage of reactance	5
E_r	—converter ring or armature voltage	95 or 105
E_b	—total reactance voltage	18.2

It is evident from a comparison of the two figures that the total reactance of each type of equipment is approximately the same.

Fig. 12 shows the inherent regulation of synchronous booster and field-controlled converters for several equal voltage ranges. For the synchronous booster type 7½ per cent reactance is assumed for transformer and low-voltage connections. For the field-controlled converter 2½ per cent is assumed for the low-voltage connections (60 cycles may be 3½ to 5 per cent) and the additional reactance in the transformer required for the several voltage ranges.

It should be noted that the inherent regulation of the 5 per cent field-controlled converter is no greater than the 5 per cent synchronous booster converter. Slightly different assumptions of reactance and resistance would make little change in the results.

The voltage range determines the amount of reactance and reactive current, and the converter is designed to carry this current at full load. At fractional loads, it may be increased, with a corresponding increase in the voltage range without exceeding full-load armature heating. Fig. 5 shows additional marking on a d-c. ammeter scale to indicate the maximum reactive kv-a. permissible at any load.

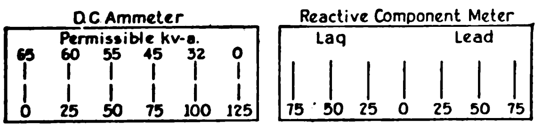

FIG. 5—MARKING OF D-C. AMMETER SCALE TO SHOW THE OPERATOR THE CAPACITY OF THE CONVERTER

The field-controlled converter at unity power factor is a simple converter and the commutation requirements are as previously described. When the power factor is leading, there is a change in the armature reaction which demagnetizes the commutating pole; the converse is true for lagging power factor. To neutralize this effect, a second winding is required on the commutating pole. This winding is approximately 10 per cent of the series winding on a converter of average proportion used for a 5 per cent voltage range by field control. The disturbance in the armature reaction is proportional to the reactive current which, in turn, is proportional to the main field current. The second winding is, therefore, excited and controlled from the main field rheostat.

The shunt-wound converter can be operated with equal stability over a greater range of reactive current and with more reactance in the a-c. circuit than the compound-wound machine. The usual design of 250-volt converter gives about 50 per cent reactive current at no-load and with zero field. To get the best efficiency over the voltage range, maximum obtainable reactive current is used at no-load minimum

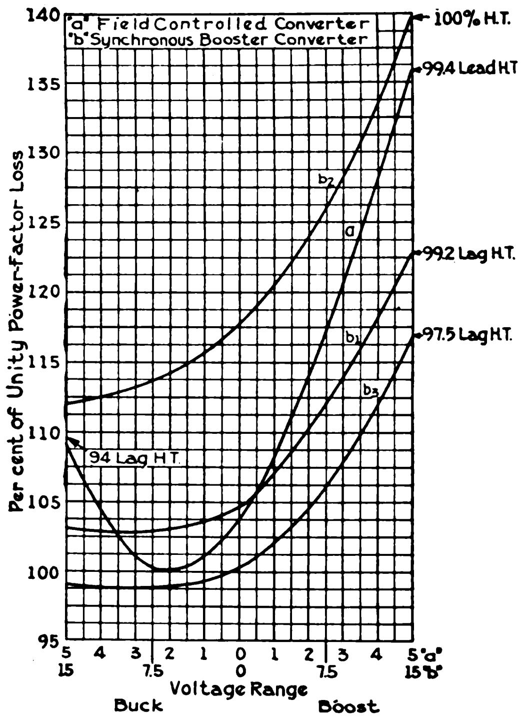

FIG. 6—COMPARISON OF $I^2 R$ ARMATURE LOSSES OVER THE VOLTAGE RANGE OF THE FIELD-CONTROLLED AND THE SYNCHRONOUS BOOSTER CONVERTER WITH UNITY POWER FACTOR, HIGH-TENSION COLLECTOR RINGS AND CONVERTER ARMATURE

voltage. The converter armature loss on this basis, over a 10 per cent voltage range, is shown in Fig. 6, Curve *a*.

Fig. 7 gives results from test showing the relation of reactive current at the converter collector rings at no-load, half load, and full load over the voltage range. The loss shown in Fig. 6, Curve *a* is based on results of test.

Fig. 8 shows the conventional voltage range, that is,

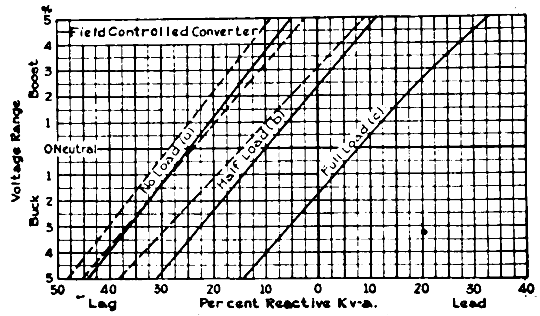

FIG. 7—RELATION OF VOLTAGE RANGE TO REACTIVE KV-A.—4200-KW. 25-CYCLE FIELD-CONTROLLED CONVERTER

the range from no-load minimum to full-load maximum; also the additional range at lower voltages with increase in load, and the additional range at higher voltages with partial loads. The curves are from test

on a 4200-kw. unit. It may be argued that only the conventional range is of any commercial value, but additional lowering of voltage under load is useful for load shifting and limiting. The higher voltage will often provide for the requirement of a higher bus on which the load is small.

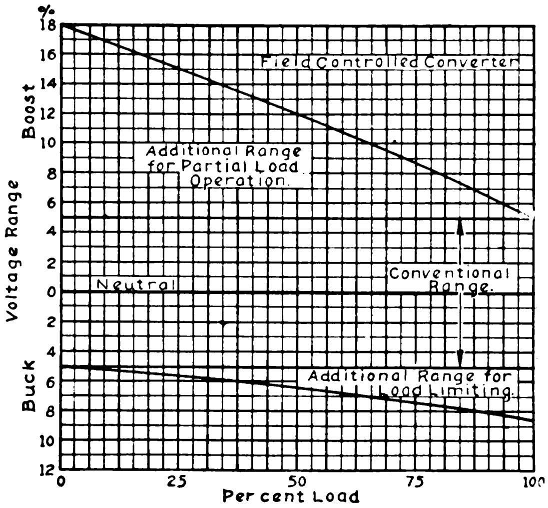

FIG. 8—RELATION OF VOLTAGE RANGE TO LOAD—4200-KW. 25-CYCLE FIELD-CONTROLLED CONVERTER

In the larger substations, three d-c. buses are often used. During light load periods, all buses are tied together, giving in effect, a 24-hour load at nearly constant voltage. (Fig. 9 low bus).

The voltage of the main and high bus is also shown. Attention is called to the voltage range indicated by x and y. This is an important consideration where a

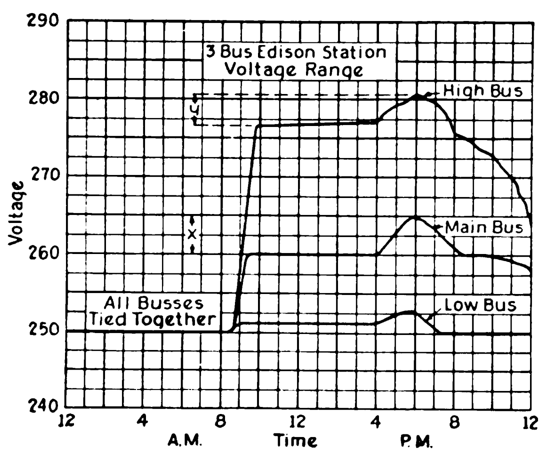

FIG. 9

number of machines are operating in parallel on a bus. The wide-range machines are connected first and the narrow-range machines are connected last and disconnected first. Suitable switches for changing the transformer connections with the transformer unexcited makes a narrow-range machine available for any bus. To change from one bus to another, the load must be removed, the transformer line switch opened, ratio adjuster operated to the desired position, machine synchronized, and loaded.

The transformer is designed for approximately 15 per cent reactance. The equipment is designed for a total range of 20 per cent (± 10 per cent) with five running points on the transformer. The available range

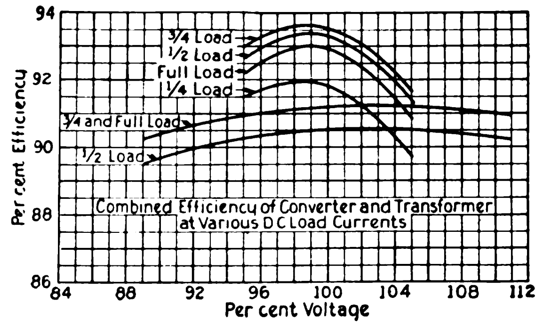

FIG. 10—COMBINED EFFICIENCY OF CONVERTER AND TRANSFORMER

Upper 10 per cent voltage range curves, 4200-kw. 25-cycle field-controlled converter equipment.

Lower 22 per cent voltage range curves, 3500-kw. 25-cycle synchronous booster converter equipment

from any running connection is 10 per cent (± 5 per cent) resulting in a very flexible arrangement. The high-reactance transformer is a very satisfactory design, and, in many cases, costs little more than the low or normal-reactance type.

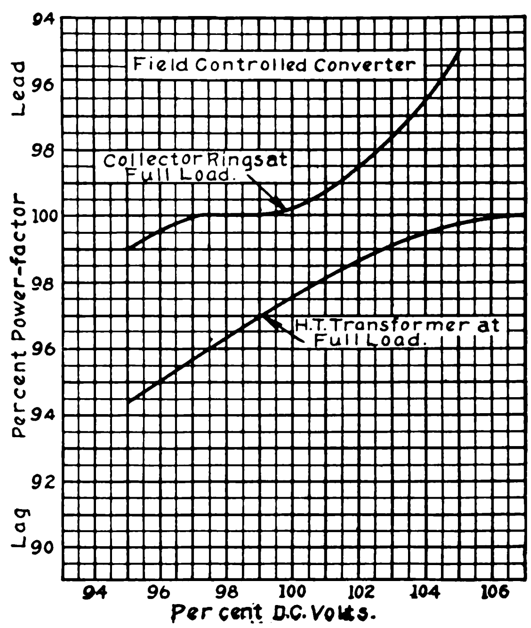

FIG. 11—RELATION OF POWER FACTOR TO VOLTAGE RANGE AT FULL LOAD, FIELD-CONTROLLED CONVERTER

The following is a comparison of the field-controlled and synchronous booster types:

1. Higher efficiency of field-controlled type as shown in Fig. 10. The values are from tests on a 4200-kw. field-controlled and 3500-kw. synchronous booster converter and transformer. The transformer efficiency

in each case is approximately the same and the loss in the low-voltage connections has been deducted. The efficiency of the types over their respective voltage ranges is shown at one-half, three-quarter and full load. The efficiency of the field-controlled converter varies considerably over the voltage range. A transformer connection should be chosen to give highest efficiency at the operating voltage.

Designing the synchronous booster converter for the same range as the field-controlled converter gives but slight improvement in efficiency because the losses in a synchronous booster do not decrease in proportion to the reduction in range.

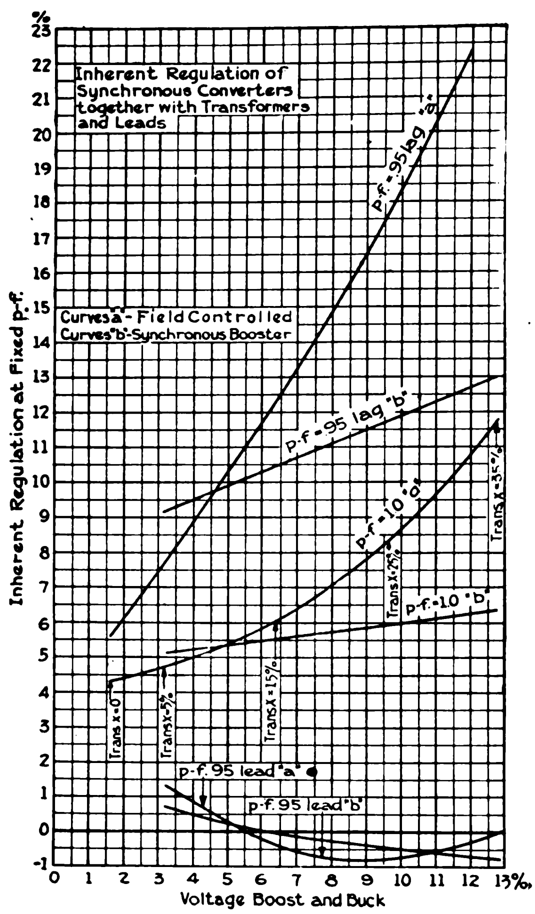

FIG. 12—INHERENT REGULATION OF CONVERTER EQUIPMENTS DESIGNED FOR SEVERAL VOLTAGE RANGES

2. Successful commutation over the voltage and load range of the field-controlled converter is obtained without the use of relays or special rheostats.

3. Better ventilation and accessibility of the field controlled converter.

4. Cost is in favor of the field-controlled converter for a voltage range not to exceed 10 per cent (± 5 per cent). The cost of the synchronous booster converter is reduced about 1 per cent in lowering the booster voltage from 15 to 10 per cent, and 2 per cent in reducing from 15 to 5 per cent.

5. Saving in floor space is in favor of the field-controlled converter.

6. The synchronous booster converter allows operating at unity power factor at the collector rings over its range of voltage; also it can be designed, at additional cost, to hold unity power factor at the transformer primary. The power factor of the field-controlled converter can not be adjusted independently of voltage, and the power factor at the transformer primary may be as low as 94 per cent lagging at full load minimum voltage, and about unity at maximum voltage. At partial loads the power factor will be lower; however, the reactive kv-a. should be considered, as it is a better guide than power factor. Fig. 11 shows the power factor at the transformer primary and the collector rings at full load over the voltage range.

7. The synchronous booster converter can be designed for a large voltage range while the field-controlled is limited to approximately 10 per cent. If the a-c. line has poor regulation (resistance drop) or is

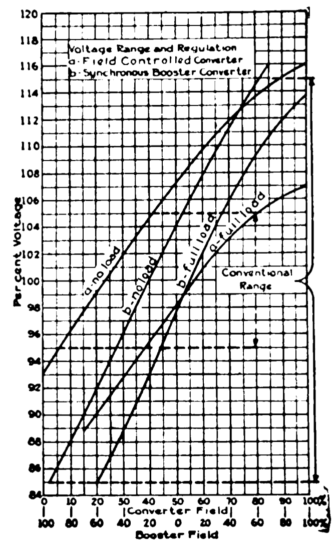

FIG. 13

subject to voltage fluctuations, the net range is reduced in proportion. The a-c. range should, therefore be considered in connection with d-c. range required, in selecting the proper type of apparatus.

8. When starting d-c., it is not possible to change the a-c. voltage of the field-controlled converter for synchronizing and the d-c. supply should be tripped immediately before closing the a-c. circuit. This method of synchronizing is desirable on the synchronous booster converter as well.

9. Simplicity of the field-controlled converter.

10. Fig. 13 shows voltage range and regulation from test on large units of each type. Close regulation is not necessary to meet requirements of Edison service, furthermore broad regulation, especially when batteries are floated on the bus, gives greater stability.

11. Fig. 6 shows the average I^2R loss in the converter armature of each type.

MODIFIED SYNCHRONOUS BOOSTER CONVERTER

The synchronous booster may be excited either by direct current in the field coils or reactive current in the armature. The field winding may, therefore, be

omitted and the field structure somewhat reduced. It is not practicable to furnish as much excitation through the armature as through the field windings and therefore this type of booster has a smaller voltage range.

The effects on commutation of the synchronous booster and field control are approximately equal and opposite for machines of equal range. Both these effects are present in the modified booster and no auxiliary commutation devices are necessary.

Transformers

Transformers for synchronous converters may be single- or three-phase, shell or core type, air-blast, water-cooled, or self-cooled.

The secondary winding is designed for low voltage with high amperage. This requires a winding consisting either of a large number of multiple coils or a helical winding containing many individual multiple strands. The first case requires multiple connections between coils and between coil groups; also provision for obtaining equal current division anong the circuits. The second case combines mechanical difficulties of coil support and of winding. A new type of coil has been developed and is now in commercial service that is well suited to large units at 25 cycles. Some 4550-kv-a. shell-type, air-blast transformers with 150 per cent load for two hours have been built using solid copper bar 7/16 in. (1.11 cm.) thick by 13 1/2 in. (34.3 cm.) wide for the low-voltage winding. This type of winding has the advantage of ideal mechanical construction, no danger from unsupported turns or strands, coils supported and braced with straight moulded channels and spacers, efficient cooling with air in direct contact with copper, small air-duct requirement, and improved space factor. There is the disadvantage of additional eddy current loss. The full-load efficiency of the 4550-kv-a. unit is 98.14 per cent. Fig. 26 is an illustration of the solid bar coil.

At 60 cycles, it is often desirable on large machines to provide twelve conductors between transformer and converter so as to obtain low reactance and uniform heating. Careful consideration should be given to the location of the transformer so that the low-voltage connections are short and properly arranged to give minimum losses. The transformer may be placed below the converter. For the minimum length of low-voltage connections the air-blast transformer can be placed immediately below the converter on its side to simplify the problem of ventilation.

Dynarotor

Low-voltage connections between transformers and converters are costly in large size units, and considerable loss and reactance are found in many cases. The motor generator has the advantage in this respect. Going a step forward, the motor and generator can be combined into one machine using a common armature core; and going a step backward with the synchronous converter, the direct and alternating current may be carried by two separate windings in a common core. The a-c. winding may be designed for the voltage of the bus not to exceed 13,200 to which it is connected through a suitable collector. The d-c. winding connects to a commutator. By providing a leakage path for flux between the two windings, reactance is obtained, and voltage range is obtained as

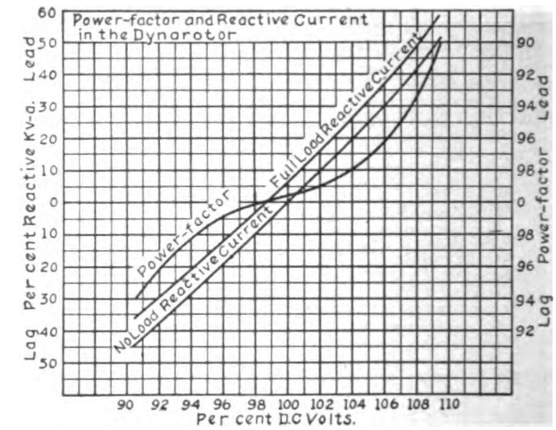

Fig. 14

in the field-controlled converter. The commutating-pole field strength is effected and compensated for as in the field-controlled converter.

There are certain apparent limitations due entirely to the usual forms of construction. The high-voltage a-c. winding is difficult when built on a rotor, especially if the voltage exceeds 6600. Since the a-c. and d-c. windings are in common slots, a failure in the bottom winding involves removing both windings for repairs.

The over-all efficiency of such a unit is slightly

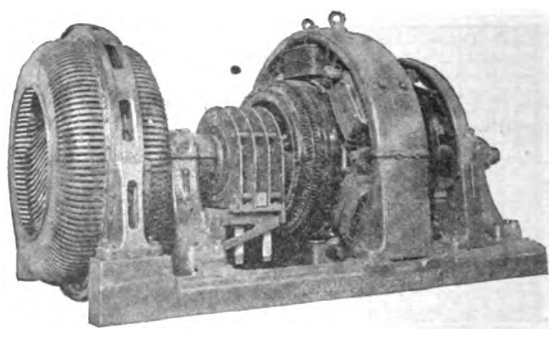

Fig. 15—1000-kw. 6600-Volt Three-Phase 250-Volt D-C. 25-Cycle Dynarotor with Synchronous A-C. Booster

higher than the synchronous booster converter with its transformer and connections, higher than the motor-generator, but lower than the field-controlled converter and transformer.

Fig. 14 gives characteristic curves from actual test on a 1000-kw. 250-volt unit. Fig. 15 is an illustration of the unit with a-c. synchronous booster. The booster was removed before the machine was installed since the necessary voltage range was obtained without it.

A-C. Starting

There have been no recent important developments in direct-current, induction-motor or secondary-tap starting. High-tension starting simplifies the low-voltage connections and eliminates heavy current switches.

Three methods are available: series-multiple, *Y*-delta and extended primary windings. Series-multiple offers the greatest advantage on two-phase-six-phase transformation; *Y*-delta on three-phase-six-phase, and extended-primary windings in conjunction with reactors for switching under load.

Y-delta is the cheapest. It requires two triple-pole switches only when 58 per cent starting voltage is suitable. For other voltages three primary taps must be added. The connections should be so chosen that the time phase displacement of 30 electrical degrees between the *Y* and delta connections will allow the converter armature to drop back a certain angle depending on the ratio of its losses to stored energy. This reduces the 30-degree phase displacement.

The starting kv-a. will be the same with low-tension or high-tension starting. The kv-a. on switching to full voltage depends on the voltage and phase difference of supply and converter. If the time in switching were zero, then the low-tension starting would have the advantage with no phase displacement against 30 degrees for *Y*-delta. The time in switching tends to equalize this difference.

Fig. 16 is an oscillograph record of the current in starting and switching, for secondary-tap starting, on a 2500-kw., 60-cycle, synchronous booster converter. The kv-a. at the instant of start is 150 per cent, dropping immediately to 110 per cent. On switching to full voltage, the inrush is 110 per cent. As a matter of interest, the complete starting and switching event is shown.

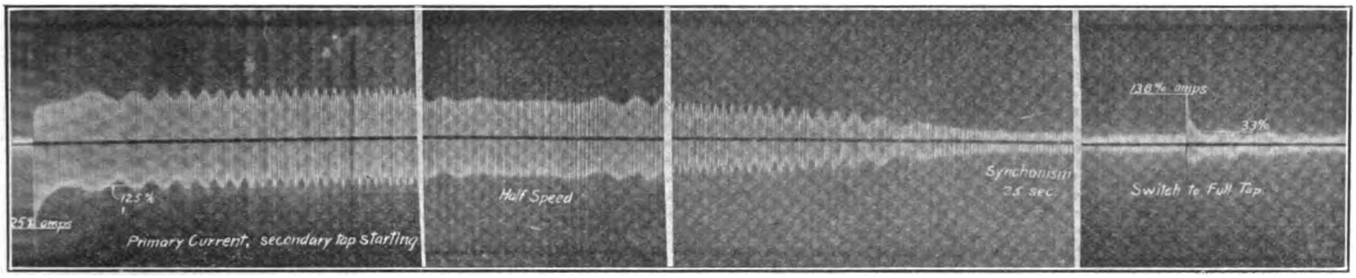

Fig. 16—Oscillograph Record, Secondary-Tap Starting, 2500-kw. 60-Cycle Synchronous Booster Converter

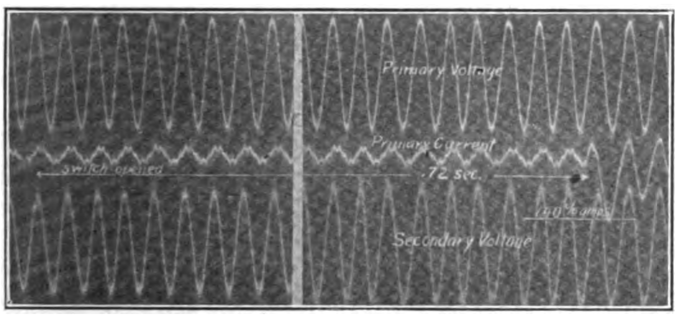

Fig. 17—Oscillograph Record, Secondary-Tap Starting, 2500-kw. 60-Cycle Synchronous Booster Converter
Switching from 75 per cent tap to full voltage

Fig. 17 shows the time of switching (0.72 sec.), also the phase displacement between line and converter, amounting to 20 electrical degrees behind.

Fig. 18 is an oscillograph record of starting current, for *Y*-delta high-tension starting, on a 3700-kw., 60-cycle, booster converter. The inrush kv-a. is 100 per cent, dropping immediately to 69 per cent. The inrush on switching to full voltage is 75 per cent.

Fig. 19 shows the time of switching (0.38 sec.), also the phase displacement between line and converter amounting to 20 electrical degrees ahead.

Fig. 20 shows that there is no noticeable effect on the voltage of the system (140,000-kv-a. connected capacity) when a 3700-kw. 60-cycle unit is started.

Motor-Generator

In selecting between synchronous motor-generator or synchronous converter for Edison service, costs, floor space, efficiency, parallel operation with existing apparatus, and synchronous condenser capacity have been the determining factors. The characteristics of the two types of apparatus are, however, radically different under certain conditions. The converter once out of synchronism with the supply can not remain connected to the d-c. system because of its

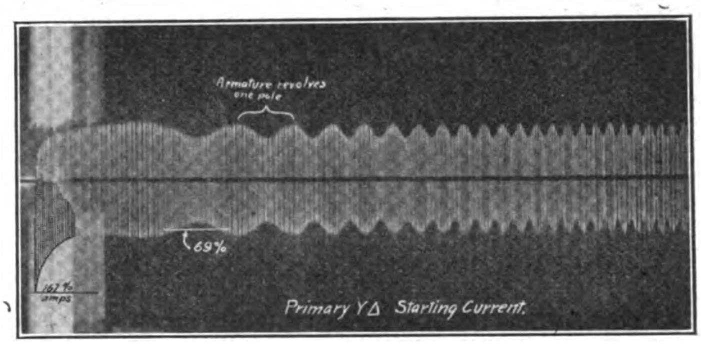

Fig. 18—Oscillograph Record, High-Tension *Y*-Delta Starting, 3700-kw. 60-Cycle Synchronous Booster Converter

changing polarity. The synchronous motor can drop out of step without affecting the generator in any way except to drop its speed and therefore its voltage and load.

Motor-generator sets now in operation on Edison systems have not been designed with special regard to load limiting of the generator or a-c. starting and synchronizing of the motor. Generators in the main have been built shunt-wound, a few compound-wound and a number with series windings for differential-genrateor or compound-wound motor operation. The differential generator was thought necessary for succesful parallel operation with batteries, but in actual practise it has been found that the regulation of the generator operating shunt-wound with series winding short-circuited is sufficient to give the desired results under normal conditions. Under abnormal conditions, however, it would be desirable to make use of this winding controlled so as to bring it into action on overload or reverse current to give increased stability.

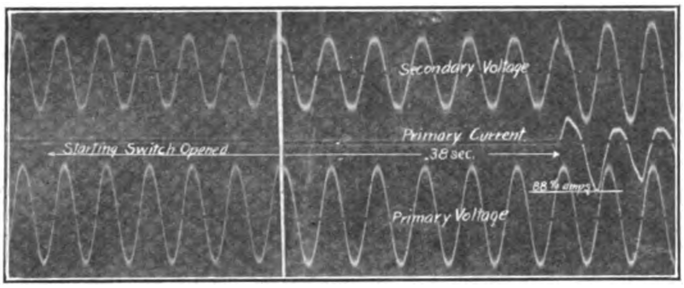

Fig. 19—Oscillograph Record, High-Tension Y-Delta Starting, 3700-kw. 60-Cycle Synchronous Booster Converter

Switching 72 per cent to full voltage

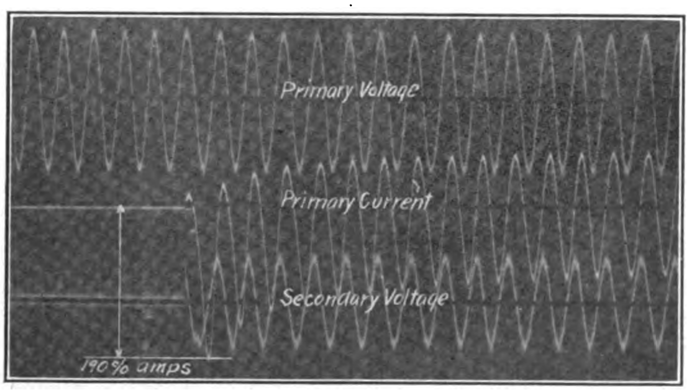

Fig. 20—Oscillograph Record, High-Tension Y-Delta Starting, 3700-kw. 60-Cycle Synchronous Booster Converter

Both generator and motor designs have advanced to the stage where certain desirable characteristics can be obtained at reasonable cost.

The synchronous motor can be designed to give sufficient torque to synchronize with full load on the generator. Figs. 21 and 22 show the relation between available motor torque and torque required by the generator, from which it is clear that the motor will synchronize with full load on generator if the supply voltage is normal. Reactance is connected in the motor circuit so that, in restoring service, full voltage may be impressed. The kv-a. required for starting with such an arrangement is high and would be warranted only under abnormal conditions. The usual switching arrangement with compensator would be used for normal starting duty.

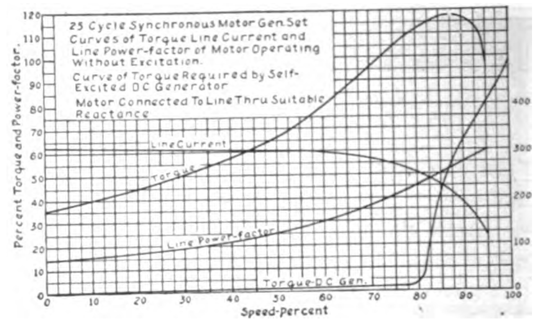

Fig. 21

The amount of reactance required for the 60-cycle motor would increase the cost of the set from 2 to 3 per cent, and lower the efficiency from 0.1 to 0.3 of one per cent. At 25 cycles, from 4 to 6 per cent in cost and 0.25 to 0.5 of one per cent in efficiency. The loss in the reactor under normal conditions could be eliminated by use of a short-circuiting switch, the switch controlled to open for or under abnormal conditions.

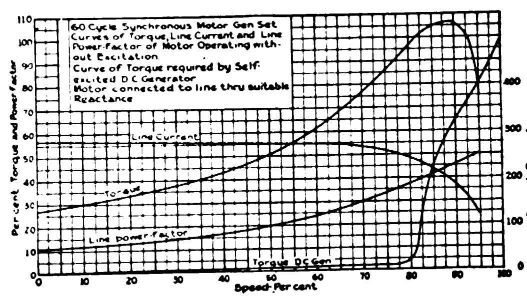

Fig. 22

The motor torque shown is that of the amortisseur winding. The motor field should be energized at about 95 per cent of synchronism, giving additional torque at the higher speeds, and finally synchronous torque. Below this speed, the torque would be greatly reduced if the field were excited.

The field circuit of the motor is controlled by a device that is responsive to "slip" between the motor and the supply; adjusted to open the motor field circuit at a predetermined slip and close it at a slightly higher value. This scheme makes available the maximum motor torque at all speeds.

The stator winding is protected against overheating by a thermal relay, the amortisseur winding by a time setting; that is, when the motor field is opened due to slip a time-delay relay will allow the motor to run as an induction motor for a definite time (probably three minutes.) If the motor field does not re-energize indicating synchronism, the time-delay relay will function to open the generator or motor connection to the line. The torque required at no-load is so small that any voltage that will start the set will bring it to synchronism. Also if the set is running at a voltage not sufficient to bring it to speed at no-load, the amortisseur winding will not overheat for a considerable period of time. If the motor field is re-energized in the predetermined time, then the time-delay relay resets and is ready for the next operation.

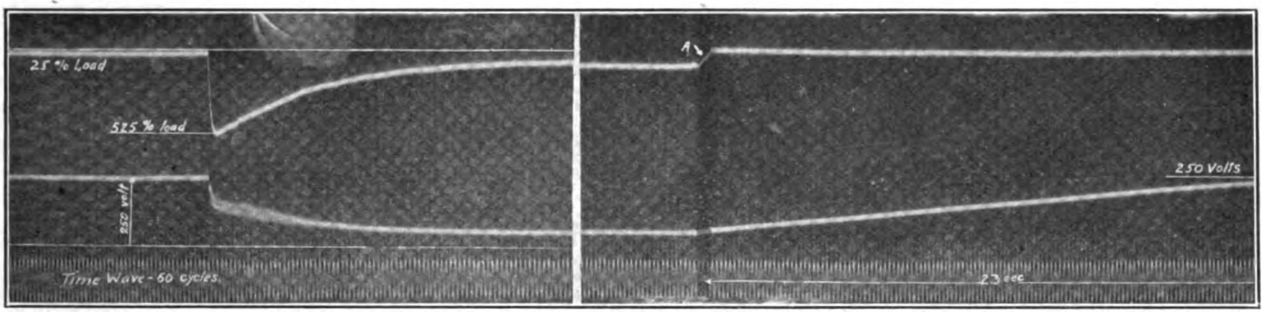

FIG. 23—OSCILLOGRAPH RECORD, SHORT-CIRCUIT TEST ON A 1000-KW. GENERATOR

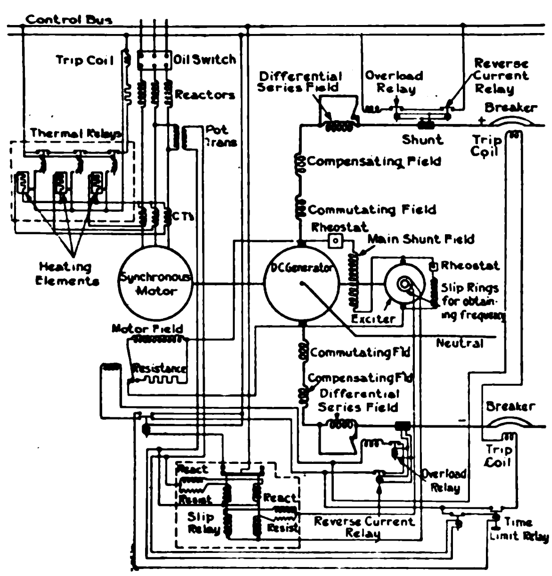

FIG. 24—SPECIAL CONNECTIONS OF SYNCHRONOUS MOTOR-GENERATOR SET FOR EDISON SERVICE

Disconnecting the generator, the motor, or both, from the line to protect the amortisseur winding of the motor gives a definite protection against dangerous heating. To insure synchronizing at voltages less than normal and thereby feeding the d-c. system all the available power an unloading control for the generator (not shown in Fig. 24) is used. A motor-operated rheostat of suitable resistance is connected in series with the shunt field of the generator and is controlled by a double acting instantaneous relay which is energized simultaneously with the time-delay relay used for disconnecting the generator from the line. This causes a lowering of voltage and current until the motor synchronizes. The speed of the rheostat is very slow so as to reduce the generator output a minimum amount for the motor to pull into step. With the closing of the motor field the unloading rheostat resistance is slowly cut out, giving normal field circuit resistance.

The generator characteristics can be made such as to limit its output in current, and withstand a short circuit at its terminals without flash-over. Fig. 23 shows an oscillograph record of current and voltage of a 1000-kw. 250-volt generator with connections as shown in Fig. 24.

This scheme of connections gives generator characteristics that limit its current output at any voltage from zero to normal that a system may require. The generator is arranged with a series winding that is connected in opposition to the shunt winding and normally short-circuited. The shunt winding is connected to the generator and exciter terminals connected in series. The generator is therefore, partly self- and partly separately-excited. The separate excitation gives stability and the self excitation and differential series excitation give elasticity to the system of voltage and current control. The separate excitation is balanced against the series differential excitation to give a limited output in current on short circuit (usually 125 per cent on continuous rated machines). Where generators are operated in parallel with batteries, exciters are not necessary.

Fig. 25 gives the characteristic curves of a generator with connections as shown in Fig. 24. Voltage in this case is automatically held constant up to full load, beyond which no further change is made in field rheostat setting. The short-circuiting device of the series differential winding opens, giving an initial drop in voltage and load. With a further reduction in resistance of the external circuit, the voltage gradually decreases to zero and the current increases

but slightly. This characteristic is required of a machine that is to be connected to an Edison system after a complete interruption of power (bus voltage zero).

Fig. 23 gives results as measured by oscillograph of a short circuit on the generator. The test simulates a short circuit on a d-c. system near the substation in which the generator is installed. The current increases to 525 per cent load instantly, then decreases to a constant value of 110 per cent load. The short

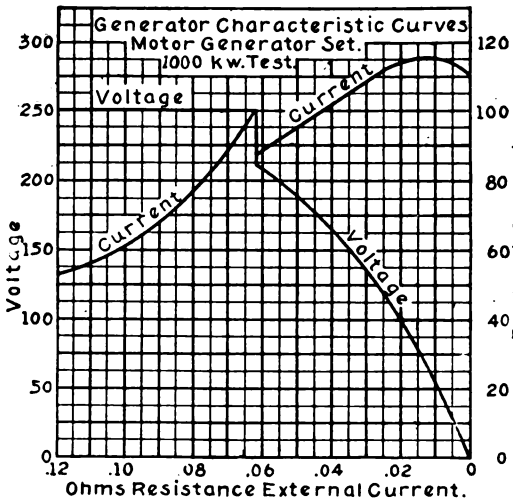

Fig. 25

circuit is removed at A. The current drops to zero and reverses. The generator operates as a compound-wound motor until voltage is restored approximately to normal.

The motor-generator with such characteristics will give continuity of service on an Edison system equal to that of the generating system supplying the power. The motor-generator, therefore, supplements the storage battery and can be used to reduce the amount of battery capacity required to give a system protection against a momentary interruption of a-c. supply.

Alternating-current power systems are constantly being developed to give continuity of service, also to localize the effects of disturbances and promptly to clear the fault from the system. Each improvement made in the a-c. system is reflected directly in the Edison system if the motor-generator is used. This does not mean that all conversion apparatus must be of the motor-generator type. A very careful study of any system will be necessary to indicate the proper capacity relation of converter, motor-generator, and storage battery to meet a desired service.

Restoring service on an Edison system after a complete shut-down is promptly and smoothly accomplished by the motor-generator set after the restoration of a-c. voltage. Each set connects to the d-c. system, delivers a predetermined amount of current and, as additional units connect, the voltage will increase until normal conditions are reached.

In general, the efficiency of the motor-generator at full load is approximately 2 per cent lower than the synchronous booster converter equipment, and at half load about 5 per cent. Floor space is about equal at 1500 kw., in favor of the motor-generator in smaller sizes and in favor of the converter in larger sizes. The difference is considerable at 4000 kw. The motor-generator is cheaper and more efficient as a three-unit set above 1500 kw. capacity. Generators controlled as shown in Fig. 24 can be connected permanently in parallel, which simplifies the switch-gear.

Automatic Substations

The advantages of automatic operation of substations for railway work have been fully demonstrated during the last six years, as is evidenced by the rapid increase in the number of such installations. Semi-automatic, remote control was demonstrated at Detroit in 1912 in the application of a 500-kw. synchronous converter equipment for lighting and power work. Edison systems to date have taken little or no advantage of developments for automatic control of conversion apparatus. The economy of the automatic substation for the interurban electric railway was obvious; its application to railway substations for city work was questioned and after six years, this

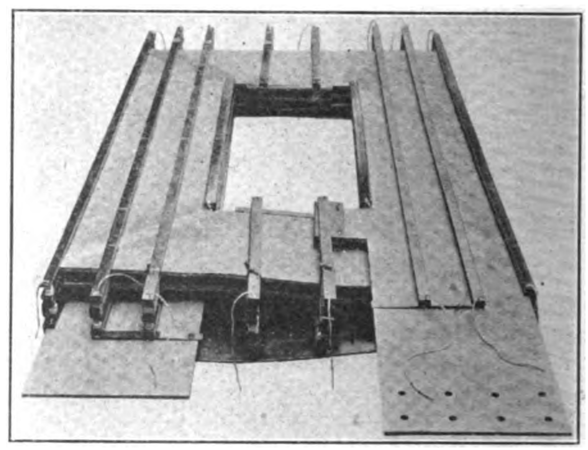

Fig. 26—215-Volt Secondary Coil and Insulation, 4550-kv-a. Air-Blast Transformer

field is being developed. The Edison substation differs but slightly from the latter, and, in the case of several moderate-size systems where a complete analysis has been made, the automatic operation of the entire system is not only favorable but highly desirable. In one case, it was necessary to vacate existing substations and change all converting apparatus to operate from 60 instead of 25 cycles. Here the a-c. system was developed and protected sufficiently to warrant the omission of batteries provided the automatic substation could be depended upon to handle the situation normally and under any emergency.

In another case, the main substation was located on very valuable property. By sub-dividing a saving

can be made in substation and property cost, in addition to a large saving in distribution losses and operating costs.

Every system has its specific problems. There are large substations located in high load-density areas where automatic operation is neither desirable, economical or advisable; there are stations where duties aside from operating would require attendance, but there is probably a place on every Edison system for an automatic substation.

The existing d-c. area may be encroached upon by the a-c. system because there is not enough load for an additional manually operated station, because feeder losses are high to the nearest d-c. substation, or because a booster or special machine would be required at the existing substation; yet d-c. service might be very desirable in such a locality. The automatic substation is the answer.

The operator who goes about his duties quickly, makes every move with precision and accuracy, is not confused by emergencies, exercises good judgment and is constantly alert to the situation, is too valuable a man for operating, and such insurance can be given the apparatus and service by automatic control. Confidence in the operation of automatic substations comes with experience in operating them.

The small and medium-size automatic substation would be provided with load-limiting equipment. In case of complete shut-down of the system the automatic substation starts promptly on the return of a-c. power, connects to the d-c. system and delivers its full current output, raising its voltage as the system permits until normal conditions are restored. For larger automatic substations, conversion apparatus with sufficient voltage range for load shifting when converters are used, and individual feeder protection by a suitable form of re-closing device, will be the most economical arrangement if the capacity of such automatic substations is not essential in restoring service after a complete system shut-down.

The automatic substation can at times be justified by the saving in operating costs, if converters are used and no-load limiting equipment is required. To secure the maximum return, however, the substations and distribution should be worked out to give a proper balance between cost of losses and capital investment.

No-load limiting equipment is required in the case of the motor-generator set as has been described. Also the motor can be designed to give motive power under all except the most abnormal conditions of power supply. This form of conversion apparatus is therefore very suitable for automatic substation application.

Load-limiting equipment for the converter is most economical in the form of series resistance. The type of resistor depends on the machine capacity and the number of steps required. In general, above 500 kw., water cooling is provided if resistance metal is used; metal resistance with suitable short-circuiting device if the number of steps does not exceed four and the current capacity does not exceed 19,000 amperes. A liquid rheostat with an infinite number of steps to the point of short-circuiting is used for higher capacities or more exacting requirements. Provision should be made to exhaust the vapors from the substation with either of the latter forms of resistors.

The authors desire to express their thanks to Mr. E. O. Shirley for help in preparing this article.

MAXIMUM ALLOWABLE WORKING VOLTAGES IN CABLES

Correction

In the article, "Maximum Allowable Working Voltages in Cables," by Davis and Simons, JOURNAL of the A. I. E. E., January, 1921, Fig. 2 on page 13 was incorrectly published, and a corrected Fig. 2 is shown herewith. The text of the article stated that the maximum stress in a three-conductor cable occurs at the surface of each conductor, and at that portion of the surface which is *nearest the center* of the cable. Fig. 2 was intended to illustrate this point, but unfortunately the arrows showing the location of the maximum stress were placed on the line of centers between conductors instead of at the points nearest the center of the cable, as correctly shown in the accompanying figure.

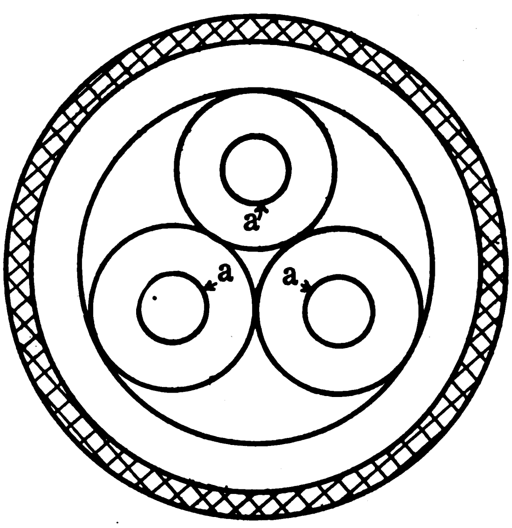

FIG. 2

(a) Shows location of maximum stress under three-phase voltage.

Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils

BY CARL J. FECHHEIMER

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It has long been recognized that the heat generated in embedded armature conductors by the I^2R and eddy current losses in part escapes by transverse flow through the insulation from the copper to the iron (possibly, to a more limited extent, to the air at the ducts) and in part flows longitudinally along the copper to the ends of the coils exposed to the cooling air. The importance of a solution of the combined transverse and longitudinal heat flows has been realized, for upon these the internal copper temperatures must necessarily be dependent. Thus, it has long been known that in a machine of short core length, the iron temperature and temperature at the center of the machine by detector between coil sides could usually be reduced by increasing the volume of air blown upon the ends, but in machines of long lengths (say 50 inches or more), the temperature at the middle could not be so reduced. Again, it has been recognized that as a machine of a given diameter is lengthened, assuming a short core length (say 10 inches for the shortest) the temperatures increased, although the losses per inch of length remained nearly the same.

Nor is a knowledge of the maximum copper temperature, (say at the middle of the machine), the only temperature that is of importance. Some of the large a-c. generators of today are designed for maximum copper temperatures of the order of 150 deg. cent. and then, whether or not the core length be great, the temperature of the copper at the end of the core may be above 105 deg. cent., which temperature may reduce the life of the fibrous insulation which is used on the end windings starting near the end of the core.

Inasmuch as designing and operating engineers are interested in the linear expansion of the straight part of the armature coil due to temperature changes, and are consequently interested in the average temperature of the length of the coil located in the armature slots they may find one of the derived equations (**33a**) to be of value. Again equation (**33**) gives a means of calculating the average temperature of the entire winding, that is, the temperature as measured by the change in resistance.

The maximum copper temperature has usually been taken as the iron temperature plus the drop through the insulating wall, the influence of the temperature of the copper upon the I^2R loss being assumed, and possibly the calculation is then repeated to allow for the new value of temperature. In this paper the condition for infinite length gives an equation (**13**) which brings in the temperature coefficient. The longitudinal flow has been solved by a number of engineers on the basis of constant losses; and Symonds and Walker have taken account of the temperature coefficient.[1]

As is subsequently shown in this paper, none of the above equations is complete, and a general determination of the internal temperature cannot be obtained with any reasonable degree of accuracy (except the maximum and minimum temperatures in long machines) parenthesis unless the simultaneous transverse and longitudinal flows be considered. A solution of that problem is offered in this paper, and it is hoped that the equations may be useful to the designer who is frequently confronted with decisions in regard to the temperatures of the embedded copper in the armature. So far as is known, there are no other formulas published today which are solutions of this problem.

The mathematical solutions offered in this paper were derived a little over three years prior to the writing of the paper, but they were not published at an earlier date, because there were no experimental data available to check calculated temperatures along the copper. The mathematical solutions and data on the experimental checks are both given in this paper.

Method of Attack

The method of attack employed in this paper consists in solving two independent differential equations for heat flow, one for the embedded part of the coil and the other for the end winding, and then combining these two solutions at the point common to the two, viz., the copper at the end of the core. The method of combining the two solutions consists in equating the heat flowing longitudinally from the embedded part at the end of the core to the heat received by the end windings at the same point; in other words, the slopes of the two curves are equal at that point. In general, the temperature of the copper is at its maximum value at the center of the core, so that point is taken as zero for X; similarly the minimum temperature is usually not far from the extreme end of the end winding, and that point is chosen as zero for the independent variable for that part. (This is discussed further under

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1. The equations derived in this paper reduce to the above. Thus, equation (**14**) gives the temperature drop considering only the transverse flow and neglects the temperature coefficient. Equations (**35**) and (**36**) are the usual longitudinal heat flow equations, neglecting temperature coefficient, and equations (**37**) and (**37a**) are for longitudinal flow taking the temperature coefficient of resistance into account.

"The points of Maximum and Minimum Temperature"). Then, considering the total heat generated by I^2R and eddy currents between the zero of reference (point one) and some other (second) point longitudinally as being equal to the sum of the transverse flow between those points and the longitudinal flow beyond the second point, the fundamental equations are easily written.

All of the equations are based upon the conditions which obtain after the steady state has been reached. Consideration of the additional independent variable, time, changes the ordinary differential equations to partials, and complicates them so much even with constant iron temperature, that a solution in practical form has not been obtained. Although the partial differential equations are linear, and admit of integration without difficulty, the combination of the equation for the ends and slot portion bring about equations which are too complicated to be employed readily.

The Iron Temperature

In writing the equations for transverse flow, it has been assumed that the temperature of the iron adjacent to the outside surface of the coil is known. For most machines, especially those of short core length, it is sufficient to consider this temperature as the average of the temperatures axially, and the first equations are worked out on that assumption. However, it is realized that in some of the longer machines, this assumption may not be admissible and that the iron temperature may perhaps approximate a straight line relation with the length, reaching its maximum value at the center of the core; whereas, in other machines, the axial distribution of iron temperatures may not be far from a parabola, again with the maximum temperature at the center of the core. Equations have been solved in which all three assumptions of distribution of iron temperature have been considered. The general method of solution is the same for all three. Inasmuch as the assumption of constant core temperature is the one which, in all probability, will be used most extensively because of its greater simplicity and sufficient accuracy, the supplementary derived equations are given for that case only.

It is hoped that methods for predicting the iron temperatures with greater accuracy than at present will be forthcoming. Such methods will probably include the rate of generation of heat in the various parts of the iron, the rate of flow of heat from the embedded copper to the iron, the transfer of heat from one part of the iron to another, and finally the dissipation of heat from the iron surface; the constants for which, must of course, be determined experimentally. In the meantime, however, it should not be difficult to secure fairly complete data of the tooth temperatures of machines, having stationary armatures of various proportions, by means of, say, embedded thermocouples placed between laminations. Such thermocouples should be so placed as to give information axially and radially; for with the deep slots employed at present the variation in temperature of the iron radially is not always negligible. If the upper coil in the slot (the one nearer the air gap) has materially higher eddy current loss than the lower, and if in addition the temperature of the tooth adjacent to the upper coil is at somewhat higher temperature than the portion of the tooth adjacent to the lower coil, the upper coil will be at higher temperature as a result of the influence of both effects. In the machine, the tests of which are given in this paper, the lower temperatures of the lower coil are due almost entirely to the lower temperature of that part of the tooth. Fig. 11 gives an idea of the variation of tooth temperature with depth. Undoubtedly, this variation in tooth temperature was largely due to the not inconsiderable difference in induction density at the different depths; (the diameter of the machine was quite small).

In many machines, it will possibly be sufficient to take as the iron temperature that of the core measured in the ordinary way by thermometer; a small correction may be added. This should apply to machines like many of our standard induction motors and low-speed alternators having shallow cores and teeth, in which the temperature gradient radially cannot be very great. In the paper "Some Practical Experience with Embedded Temperature Detectors[2]," data are given on a 12,000-kv-a. alternator, in which the average difference between detector readings near the back of the core and in the core at nearly full load was only about three deg. cent.

In employing the temperature figures for the iron, allowance may be made for the cooling of the outside of the coils in the vent ducts in radially ventilated machines. In this calculation, the following should be allowed for:

1. The increase in temperature of the air above the ingoing air;
2. The difference in temperature between the outside coil surface and the air impinging upon it;
3. The weighted mean of the iron temperature and the outside coil surface.

1. More specifically may be approximately determined by considering the losses absorbed by the air before the air encounters the coil; (remembering that the air rise is about one deg. cent. when 1765 cubic feet per minute absorb one kw.).

2. May be approximated by means of an equation like (38) in this paper.

3. The weighted mean for constant core temperature is equal to:

$$\frac{\text{Width of vent} \times \text{av. temp. of outside of coil} + \text{width of iron pkg.} \times \text{av. temp. of iron}}{\text{Width of vent} + \text{width of package of iron}}$$

In general, a rough approximation is sufficient. The cooling of the outside coil surfaces at the vents tends to introduce irregularities in the copper temperature

2. See paper by F. D. Newbury and C. J. Fechheimer, A. I. E. E., June 1920.

curve, but the high thermal conductivity of the copper undoubtedly practically obliterates them.

Eddy Currents

In most large a-c. machines, and in some d-c. machines the eddy current loss due to the load currents may augment the $I^2 R$ loss materially. This loss is not the same for the two coil sides in a slot, and is lower in the end windings than in the embedded part. The formulas derived by Mr. R. E. Gilman[3] are quite accurate but they necessarily involve the temperature coefficient of resistance of copper. In using the equations derived in this paper, it is first necessary to calculate the eddy current factor, and for this a first approximation of the copper temperature must be employed. The eddy current factor in the equations is considered to be constant, and its values should be calculated with the use of the average temperature of the copper in the slots or ends, as the case may be.

It is of interest and value to note that the length of the core of the machine is not the only factor which affects the difference between the maximum temperature as computed by transverse flow only, and the maximum copper temperature which actually obtains. If the section of copper be large,(that is, so large as to secure a nominally low density) but the eddy current loss in the embedded portion be high, the large cross-section of copper permits of flow of heat at a fairly rapid rate to the ends; consequently, even for long core lengths, the longitudinal heat flow may be quite effective in reducing the copper temperature at the middle of the machine. Thus, in a machine, which was built about ten years ago, the nominal density in the copper at full load is 1200 amperes per sq. in., and the calculated eddy current loss plus $I^2 R$ is a little more than twice the $I^2 R$ loss. Even though the core length of that machine is 58 inches, the longitudinal heat flow lowers the temperature, as calculated by means of equations in this paper, 50 degrees below the temperature calculated by means of the transverse equation (on the basis of no longitudinal heat flow).

Thermal Conductivities

The most unsatisfactory constant which is involved in equations of heat flow in electrical machinery is that of the transverse thermal conductivity of the insulating material. Unlike the electrical conductivity of metals, we are never sure within a large percentage what value to choose. Thus ordinary fish paper has been found to vary in transverse conductivity from 0.0047 to 0.0064 watts per sq. in. per deg. cent. When built up in wrappers, with say the addition of mica, such as used on the straight parts of some coils, the combined conductivity is materially reduced, (due to the introduction of short paths of low conductivity from layer to layer), and the variation in conductivity is greater than that of paper or other material[4]. For the ends, for which varnished cambric is used, with varnish between layers, which varnish reduces the influence of air pockets and contact resistance, the conductivity is higher, and the variation less than for the embedded portion.

Owing to the fact that a slight amount of volatile matter is driven off at the higher temperature, the thermal conductivity may change with time, especially if the machine be operated at temperatures above 100 deg. cent. The driving off of the volatile matter does not change the thermal conductivity of the individual layers of insulating material so much as it changes the structure of the insulation between layers, thereby changing the conductivity from layer to layer. Naturally, the variations are erratic.

Therefore, it is quite possible that the temperatures of the copper of machines may change slightly after having been in service for some time, and this is also one reason why the internal temperatures on the same machine differ when made under identical conditions, but on different days.

Furthermore, for most insulating materials, the conductivity changes with the temperature, increasing slightly with increasing temperature. When built up in wrappers, the value of the temperature coefficient of thermal conductivity is quite indefinite and on some tests, its value has been found to be zero. In the equations, the thermal conductivity has been taken as a constant, partly because of uncertain value of the temperature coefficient but more especially because of a desire to avoid further complications in the equations.

Owing to the great importance of the transverse thermal conductivity of insulating materials, laboratory tests of the value of thermal conductivities are of great value. Such tests should be made upon a large number of coil wrappers imitating as closely as possible the conditions that obtain in the machine, and the temperatures in such tests should be maintained at values approximating those in service, and be thus maintained until constant conditions are reached.

The thermal conductivity of the copper (longitudinally) is so high compared with the longitudinal conductivity of the insulation (of the order of 1000) that the neglect of any heat flow longitudinally through the insulation may well be justified. The conductivity of copper has been taken as 9 watts per sq. in. per in. per deg. cent. in the calculations to be found in this paper, and, as in the case of insulation, the temperature coefficient of heat conductivity has been neglected. Various authorities give somewhat different figures for the conductivity of copper, and the value of 9 chosen may be a little lower than that given by most

3. Eddy Current Losses in Armature Conductors, A. I. E. E., June 1920.

4. Some data on Thermal Conductivity of Insulating Material may be found in articles by T. S. Taylor in the *Electric Journal* for December 1919, and the *Elec. World* for Feb. 14, 1920; also in paper by Symonds and Walker "Heat Paths in Elec. Mach.," I. E. E., 1912.

of them. The Smithsonian tables, for example, give, about 9.6 whereas Symonds and Walker used as low value as 7.6.

Emissivity from End Windings

Next to thermal conductivity of the insulation, the most unsatisfactory constant which is employed in the equations is that of emissivity from the end windings. Every electrical manufacturer has an enormous amount of data on temperatures taken by thermometer on the surfaces of the ends of the coils, but none of such data can be directly applied. The reasons therefor are:

1. Most of the temperatures were taken after shutdown, and some of the heat flowed out from the embedded portion of the coil, and thereby influenced the reading;
2. The temperatures of the copper inside the coils at the particular spot where the thermometers were placed were not known; and if they were known the watts per unit surface would have to be calculated from the drop in temperature through the wall of insulation and from a supposed knowledge of the conductivity of the insulating wall;
3. Most data do not give the spacing between coil ends;
4. There were no records taken of the air velocities upon which the rates of heat dissipation are very largely dependent;
5. There are no records of the angles of incidence of the air.

It is believed to be best to make such emissivity tests on suitable models in a laboratory, using dummy coil ends. A description of one set of such tests is given in a recent number of the *A. S. M. E. Journal.*[5] Those tests are far from complete, as they were made on one coil only; however, data from that set of curves should be helpful until more complete data are available.

In the equations which are given in this paper, the watts per sq. in. per deg. cent. have been taken to be constant, although with variable spacing, with supports for the coil ends at intervals, with variable air velocity, with different angles of incidence of the air, etc., that factor must be quite far from being constant; it is probable, however, that the value chosen (0.045) is sufficiently close approximation to the average value which obtained in the machine. Nevertheless, some of the departures between test and calculations may be in part due to the inaccuracy of the value chosen, and to the variability of that factor. Fortunately, in many machines in which the air velocity is fairly high, or the wall of insulation is rather thick, the variation of the emissivity factor along the coil, and the incorrect choice of its average value, do not have so much influence on the final results as might at first thought be supposed; because the drop through the insulating wall on the ends is usually of considerably greater influence than the drop from the external surface to the cooling air.

The Points of Maximum and Minimum Temperature

One of the terminal conditions for evaluating one of the integration constants for the embedded portion is that at the center of the core, or for $X = O$, the temperature is at its maximum value. This assumption is usually in fairly close keeping with the conditions that actually obtain in the machine. However, with certain constructions it may be advisable to choose some other point for that of maximum temperature. For example, in most large axially ventilated turbo generators, there are fairly large radial vent ducts near the middle of the machine. The cooling air which passes over the coil surfaces near the middle of the machine reduces the temperature there, so that in such cases, it is considered advisable to take the end of the iron adjacent to the first vent duct as the point of maximum temperature; that method has been employed in the calculations to be found in this paper.

The point of minimum temperature that has been chosen in the equations for evaluating one of the integration constants in the end windings, is the extreme end of the winding. Such assumption is quite accurate provided that the temperature curves for the upper and lower coils are identical. As is usually the case, however, the upper coil temperature in the embedded part is higher than that for the lower coil, owing to higher tooth temperature adjacent to the upper coil and the higher eddy current loss in the upper coil. If, then, the rate of cooling the ends of the upper and lower coils be the same, the point of minimum temperature is on the lower coil at a short distance from the coil-end. Thus, in Fig. 9, the test curve for the particular coil located in slot numbers 9 and 21 has been drawn in dot and dash, for the 300-ampere heat run; and it will be noted that the minimum temperature is about 28.5 inches, instead of 32.5 inches, from the center of the core.

If the difference in temperature between the upper and lower coils be considerable, it may be advisable to calculate the temperatures on the assumption that the point of minimum temperature is beyond the extremity; that is, that L_b[6] for the upper coil is greater than L for the lower coil. Otherwise, the calculated curves for the upper and lower coils will not meet at any point, a condition which, of course, must be fulfilled, in the machine. It is further of interest that the moving of the point of minimum temperature from the extremity of the winding to some point on the end of the lower coil, has the effect of reducing the maximum tempera-

5. "The Dissipation of Heat by Various Surfaces" by T. S. Taylor, abstract in A. S. M. E. *Journal* for April, 1920. The complete paper contains useful curves not appearing in the abstract.

6. L_b is the length of winding from the core to the extremity. See list of Symbo s

ture of the upper coil, and of raising the maximum temperature of the lower coil, although such changes are too small to be of consequence. In fact, if the maximum temperature is the only one sought, it is believed that the error introduced by taking the minimum temperature at the end of the winding is quite negligible in machines of usual proportions.

THE TRANSVERSE AREA

The area per unit length through which the heat flows has been taken as the average area of the part of the perimeter from which the heat is dissipated, and the corresponding perimeter of the copper. For the embedded part with two coil-sides per slot, the two sides adjacent to the teeth plus one of the other sides are taken as the area (see Fig. 2). This assumes that there is no heat escapment from the two coil sides adjacent to each other. Such assumption is not strictly correct, for as was shown in the paper on "Embedded Temperature Detectors,[7]" the heat flow to the slot-sides has an appreciable influence upon the reading of the detector placed between coil-sides in the usual way. The magnitude of such heat flow is, however, very small, compared with the total transverse heat flow. Especially when consideration is given to the uncertainty of such important factor as the transverse thermal conductivity of the insulating material, the assumption is well justified.

For the end windings, in the special case for which the solution is given, the outside surface from which the heat is dissipated (for unit length) is taken as the external perimeter of one coil; and the average area through which heat flows is taken as the average of the external perimeter and the copper perimeter. In the particular problem adjacent coils were fairly well separated, so that the cooling air was effective in reaching all sides of the coil. However, such assumption may not be admissible in some machines (as many small induction motors) in which practically no air can pass between adjacent coil ends. The areas which should be chosen for the external surface Q' and that offered for transverse flow Q_b in the ends, must be decided after study by the designing engineer.

The question has been raised as to the inaccuracy of the "average area" equation, instead of the more exact logarithmic expression. The derivations and comparisons are given in the appendix, and it is there shown that with typical high-voltage (say 13,200)dimensions, the difference is less than 1 per cent. With low-voltage insulation, the difference is even less than for high-voltage.

7. Loc. cit.

(To be continued)

EXTENSION OF DEWEY DECIMAL CLASSIFICATION APPLIED TO RADIO

A year ago the radio laboratory of the Bureau of Standards, Washington, D. C., prepared a tentative scheme of classification of radio subjects. This has now been revised as an extension of the Dewey Decimal System and is useful in classifying radio references, drawings, books, and reports. The whole subject of radio communication is put in its proper place in the Dewey Classification—621.384—but it is suggested that these figures be abbreviated to the use of the letter *R*, in a purely radio library. An abbreviated classification is provided for the use of small libraries or collections. An alphabetical index enables one to refer readily to the classification number of any subject desired.

The main headings into which the subject of radio is divided are as follows:

R000 Radio Communication
R100 Radio Principles
R200 Radio Measurements and Standardization
R300 Radio Apparatus and Equipment
R400 Radio Communication System
R500 Application of Radio
R600 Radio Stations—Operation and Management
R700 Radio Manufacturing
R800 (Vacant or to be used for non-radio subject matter)
R900 Miscellaneous Radio

It is desired to make this classification as complete, comprehensive, and usable as possible, and the Bureau of Standards will be glad to send a copy of the complete classification to any persons interested, so as to place it in the hands of those having use for it and also with a view to possible future revision.

HYDROELECTRIC POWER DEVELOPMENT IN NEW ZEALAND

In his annual report to Parliament the Minister of Public Works has announced a progressive hydroelectric power development scheme to cover the next few years, writes Consul General Alfred A. Winslow, of Auckland, New Zealand, in *Commerce Reports*. The scheme consists of a complete high-tension transmission system in both the North Island and the South Island, connecting up the different hydroelectric power centers with the many electric power board districts.

* * * * *

The potential power of the proposed hydroelectric developments in the North Island amounts to 341,000 h. p., with equal possibilities in the South Island. It is estimated that the North Island scheme will cost $50,000,000, and that the South Island plan will not fall much behind.

These developments will call for large quantities of electrical machinery and supplies, much of which might be supplied by American manufacturers if they could arrange to assist in financing these extensive schemes. . . . .

The development of these schemes will be closely watched, and later plans and specifications covering the different installations will be forwarded to the U. S. Department of Commerce. Meanwhile, communications addressed to L. Birks, Public Works Department, Wellington, New Zealand, should have early attention.—*Electrical Record.*

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. MARCH MEETING, NEW YORK

The 368th meeting of the A. I. E. E. will be held in New York, Friday evening, March 11th in the Engineering Societies Building.

The program will be under the auspices of the Power Stations Committee, and the subject of the meeting will be "Developments in Conversion Apparatus for Edison Systems" by T. F. Barton and T. T. Hambleton both of the General Electric Co. The paper is printed elsewhere in this issue. One main paper will be presented and will be followed by several prepared discussions.

FUTURE A. I. E. E. MEETINGS

APRIL, PITTSBURGH

The 369th meeting of the A. I. E. E. will be held on Saturday. April 16, 1921, in Pittsburgh, Pa. This will be a joint meeting with the Association of Iron and Steel Electrical Engineers and the general subject of the meeting will be "The Power Supply of the Pittsburgh District in Relation to the Steel Mill Industry."

Two papers will be presented on behalf of the A. I. E. E. and two papers on behalf of the A. I. and S. E. E. The A. I. E. E. papers are on the "New Colfax Station of the Dusquesne Light Company—Electrical Features" by D. L. Galusha and the "Mechanical Features" by C. W. E. Clarke. The A. I. & S. E. E. papers are "Problems of Conversion from 60 Cycles to 25 Cycle" by B. G. Lamme, and "Some Results in the Change of 60-Cycle to 25-Cycles Energy" by D. M. Petty.

The program includes a visit to the Colfax plant in the morning followed by luncheon; an afternoon session at which the papers on the Colfax plant will be presented and discussed; informal dinner, and an evening session at which the papers by Messrs. Lamme and Petty will be presented.

MAY, NEW YORK

The 370th meeting of the A. I. E. E. will be held in the Engineering Societies Building, New York, May 20, 1921. This is the Annual Meeting of the Institute, at which the result of the annual elections is announced and the report of the Board of Directors is presented. A technical program to be announced later will follow the business session.

ANNUAL AND PACIFIC COAST CONVENTION, SALT LAKE CITY, JUNE 21-24

Plans for the combined Annual and Pacific Coast Convention are progressing. At the meeting of the Board of Directors held February 16, the Chairman of the Meetings and Papers Committee reported that the committee has tentatively scheduled four technical sessions, under the auspices of the Electrical Machinery, the Industrial and Domestic Power, the Transmission and Distribution Committees, and a miscellaneous session. It is intended that these technical sessions will be held on the four mornings of the convention, leaving the afternoons and evenings open for other events.

Mr. H. T. Plumb of Salt Lake City has been appointed by President Berresford as Chairman of the Convention Committee, the complete personnel of which will be announced in a later issue. Mr. Plum and his associates of the Utah Section have already made considerable progress in planning events for the four afternoons and evenings, including opportunities for several visits to power plants, mines and other places of engineering interest; also several social events which will be of more particular interest to the ladies in attendance.

FUTURE SECTION MEETINGS

Cleveland.—March 14, 1921. Subject: "Electric Propulsion of Ships." Speaker: Mr. W. E. Thau, Westinghouse Electric & Mfg. Co. This will be a joint meeting with the Association of Iron & Steel Electrical Engineers.

Detroit-Ann Arbor.—March 18, 1921. Joint meeting with Detroit Engineering Society, to which all of the A. I. E. E. sections in the Great Lakes District, also the Toledo and Cleveland Sections, are invited. Inspection trips will be made during the day and a get-together dinner will be held at 6:30 preceding the paper of the evening. This will be "The Story of the Induction Motor," by Mr. B. G. Lamme, Chief Engineer of the Westinghouse Elec. & Mfg. Co.

Kansas City.—March 25, 1921. The meeting will be held at the Northeast Power House of the Kansas City Light & Power Company. Mr. H. C. Blackwell, General Manager of the Kansas City Light & Power Company, will give an illustrated talk on the design and operation of the power plant of that company.

San Francisco.—March 25, 1921. Subject: "A Variable Voltage Railway Converter Substation." Speaker: Mr. J. E. Woodbridge, Resident Engineer, Ford, Bacon & Davis. Meeting will be held in the new substation of the United R. R. of San Francisco.

Schenectady.—March 18, 1921. Subject: "European Economic and Industrial Situation." Speaker: Mr. David B. Rushmore.

Vancouver.—March 20, 1921. Subject: "Electrical Energy Rates." Speaker: Mr. E. E. Walker. Joint meeting with B. C. Technical Association.

April 1, 1921. Subject: "High-Voltage Transmission in British Columbia." Speaker: Mr. J. Muirhead.

THE 1921 MIDWINTER CONVENTION

The Ninth Midwinter Convention of the A. I. E. E., held February 16-18, 1921, in the Engineering Societies Building, New York, proved to be one of the most successful Midwinter Conventions of recent years, both in point of attendance and in the general interest manifested in the technical papers and discussions. The registration of members and guests totaled over 1000 names.

Wednesday afternoon was devoted to the registration of members and guests, and to trips to the plants of a number of electrical companies who courteously invited inspection by members and guests attending the Convention.

As indicating the activity of Institute work at this time, it may be mentioned that twelve committee and sub-committee meetings were held on Wednesday and Thursday during the Convention as follows: Meetings and Papers Committee, Publication Committee, Standards Sub-Committee on Insulators, Electrical Safety Conference Sub-Committee on Oil Circuit Breakers, Electrical Machinery Committee, Membership Committee, Mines Committee, Finance Committee, Transmission and Distribution Committee, Protective Devices Sub-Committee on Oil Circuit Breakers and Switches, Library Committee and Standards Sub-Committee on Telegraphy and Telephony.

Wednesday Evening

The first technical session was called to order in the auditorium at 8:15 p.m. on Wednesday by President Berresford, who delivered a brief address concerning the service of the engineering profession, excerpts from which appear elsewhere, after which he turned the conduct of the meeting over to Mr. D. W. Roper, Chairman of the Protective Devices Committee, under whose auspices the technical session was held. The following papers were then presented:

Present Day Practise Limitations of Oil Circuit Breakers. By Subcommittee on Oil Circuit Breakers and Switches of the Protective Devices Committee, H. E. Woodrow, Chairman.

High-Current Tests on High-Tension Switch-Gear, By Philip Torchio.

Moving pictures and oscillograph records of switches at the instant of failure were shown.

The papers were discussed by Selby Haar, Peter Junkersfeld, E. P. Peck, H. E. Trent, N. L. Pollard, E. E. F. Creighton, William A. Moore, and written discussion by N. J. Conrad. The authors made closure on their respective papers.

Thursday Morning

The technical session Thursday morning, which was devoted to a symposium on "Operating Temperatures of Low-Voltage Paper-Insulated Cables," was opened by Mr. W. A. Del Mar, who acted as Chairman during the session, and the following papers were presented:

The Maximum Safe Operating Temperatures of Low-Voltage Paper-Insulated Cables, By W. A. Del Mar.

Permissible Operating Temperature of Impregnated Paper Insulation in Which the Dielectric Stress is Low, by Philip Torchio.

Permissible Operating Temperatures of Impregnated Paper Insulation in Which the Dielectric Stress is Low, by D. W. Roper.

Notes on the Effect of Heat on Impregnated Paper From Cable Insulation, by W. S. Clark.

The Effect of Heat upon Paper Insulation, by H. W. Fisher.

Permissible Operating Temperatures of Impregnated Paper Insulation in Which the Dielectric Stress is Low, by L. L. Elden.

Those who took part in the discussion of the papers were Frank M. Farmer, George B. Shanklin, E. B. Meyer, W. I. Middleton, Comfort A. Adams, H. R. Woodrow, P. H. Chase, R. J. Wiseman, William Maver, Jr., Philip Torchio, D. W. Roper, A. E. Kennelly, F. D. Newbury, C. N. Rakestraw, Harold C. Dean, Dugald C. Jackson and R. W. Atkinson.

Thursday Afternoon

The session on Thursday afternoon was called to order by President Berresford, who turned the meeting over to Mr. Donald McNicol, Chairman of the Committee on Telegraphy and Telephony. Two papers were presented at this session. The first, entitled *Carrier-Current Telephony and Telegraphy*, by E. H. Colpitts and O. B. Blackwell, was presented by Mr. Colpitts. The next paper, *Some Phases of Railroad Telegraph and Telephone Engineering*, by Stanley Rhoads, was then presented by the author. The discussion which followed was participated in by Major General George O. Squier, A. E. Kennelly, E. C. Keenan, C. E. Davis, H. M. Turner, H. W. Drake and John L. Niesse.

Thursday Evening

On Thursday evening a Dinner-Dance was held in the Ballroom of the Hotel Astor, at which considerably over four hundred members and guests were in attendance. This Dinner-Dance has come to be a regular feature of the Midwinter Conventions of the Institute and has always proved a most enjoyable and popular social function.

Friday Morning

The technical session Friday morning was under the auspices of the Instruments and Measurements Committee and was presided over by Mr. F. V. Magalhaes, Chairman of that committee. The papers presented were as follows:

Regulation of Frequency for Measurement Purposes, by B. H. Smith.

Measurement of Relative Eddy Current Losses in Stranded Cables, by J. A. Cook.

An Electromagnetic Device for Rapid Schedule Harmonic Analysis of Complex Waves, by F. S. Dellenbaugh, Jr.

The Limitations of the Stopwatch as a Precision Instrument, By A. L. Ellis.

The papers were discussed by J. R. Craighead, Charles F. Scott, W. H. Pratt, J. B. Whitehead, R. W. Atkinson, F. V. Magalhaes, A. Karapetoff, H. M. Smith, L. N. Potts, with closures by the authors.

Friday Afternoon

The final technical session of the Convention was called to order Friday afternoon by W. I. Slichter, Chairman of the Meetings and Papers Committee. The first paper to be presented was entitled *Short-Circuit Current of Induction Motors and Generators*, by R. E. Doherty and E. T. Williamson. The paper was presented by Mr. Doherty. The next paper, *Hysteresis Effects with Varying Superposed Magnetizing Forces*, by W. Fondiller and W. H. Martin, was presented by Mr. Fondiller, and the final paper on *Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils*, by Carl J. Fechheimer, was presented by the author.

Those who took part in the discussion were V. Karapetoff, Lawrence E. Widmark, M. I. Pupin, Selby Haar, Charles W. Burrows, B. A. Behrend, R. B. Williamson and Carl Hering. Written discussion was also presented by N. S. Diamant, G. E. Luke and M. A. Savage.

Friday Evening

The Presentation of the Edison Medal to Dr. M. I. Pupin of Columbia University took place in the auditorium, Friday evening at 8:30 p. m. After calling the meeting to order, President Berresford said a few words in explanation of the origin of the Edison Medal and then introduced Colonel J. J. Carty, who made the presentation address. Colonel Carty described at length the work and inventions of Dr. Pupin, especially in connection with telephone industry. He paid a high tribute to the work of the medallist whose inventions have been one of the chief factors in extending the radius and

improving the quality of telephonic communication. The Medal and Diploma of Award were then presented to Dr. Pupin by President Berresford.

Dr. Pupin then gave a most interesting address, entitled "Wave Transmission," during which he described some of his early experiences in Serbia and various incidents of his life and education leading up to his telephonic inventions. In closing, he expressed his most sincere appreciation of the honor conferred upon him by the Institute in presenting him with the Edison Medal, which constituted the highest honor which the Institute could bestow.

EXCERPTS FROM ADDRESS OF PRESIDENT BERRESFORD AT OPENING SESSION

In gathering for this—our Ninth Midwinter Convention—we are fulfilling one of the stated purposes of our association, namely, the holding of meetings for the reading and discussion of professional papers, to the end that the theory and practise of Electrical Engineering and of the Allied Arts and Sciences may be advanced and that there shall be maintained a high professional standing among our members.

Gregariousness—a flocking together—is an oft-noted trait of human nature, but it becomes a dominating instinct where men possess some strong interest in common. If no American Institute of Electrical Engineers had ever been formed, we would form one tonight almost without consideration in order that we might possess facilities for the discussion of the matters which most engage our daily thought.

But whatever might be the specific object for which we associated, at some time in the course of that association we would inevitably find ourselves departing in some measure from it. Essaying some other effort—higher and less self-centered, if the fundamental motive be altruistic—meaner and narrower, if the dominant note be self-interest.

The complicated civilization of the present day exhibits this process of association at its maximum and its effects are difficult to estimate, but, without question, enormous. Each individual instance produces some effect upon the body politic, if for no other reason than that the association simply existed. Slight it may be, and either for good or evil, but inevitable. If it be in the interest of humanity, the rate of progress is increased—if contrary, it is retarded. We begin the exercise of this influence immediately we have formed ourselves into an associated body. It is utterly beyond our power to live to ourselves alone, or solely for our own objects. Whether we will or no, we at once become a factor in what shall be, and exert an influence on when it shall come to be.

If this be true of but a few men—and it is true—what care then must be exercised by an association of the magnitude of the Institute, to the end that all of our doings may redound to the good of our people, our race and the world as a whole.

Having recognized this responsibility, which became ours by the very act of association, may we nor well inquire as to our fitness for meeting it? Have we any peculiar qualification which particularly fits us, and if so, may more be expected of us than of those not so liberally endowed? It seems to me that we have. We are a body of professional men, or men on their way to become professional men. From time immemorial the professional man—teacher, minister, doctor, soldier—has been acepted on a basis of substantial equality by those of high degree and recognized as possessing uncommon qualification by those of less fortunate placing. The engineer (starting from the soldier as the military engineer, and throughout all of the diverse branches of the profession recognized today) has similarly enjoyed this distinction.

The very persistence of this recognition throughout the years indicates that it must possess substantial foundation. Mere educational superiority is not sufficient explanation and sinple self-assertion would not have given permanence.

I conceive it to reside in a single fundamental characteristic—the fact that there comes to each a moment (and in that moment he becomes truly a professional man) when the work itself—the instinct to do or to create—utterly outweighs the element of resultant personal advantage. Having once attained the experience, the mental habit becomes fixed, material concerns assume their true proportion and there results a class of men whose aims and whose ideals become accomplishment for accomplishment's sake, and whose ultimate end—although not always self-recognized—becomes the serving of their fellows.

The world recognizes the effect without seeking the cause. It perceives a man who is aiding its advancement, with subordinated self-interest and without ulterior motive, and so long as he displays these qualities holds him superior. This is the professional man, and this willingness to serve has become the fundamental tradition of his class.

The engineer has well maintained the tradition. He may not have put it into words. He may not have consciously recognized it in himself other than as a duty and as such to be accepted and performed, but his accomplishment makes evident the existence of the underlying ideal.

And there is no insignificant body of him in this country of ours. A reasonable estimate seems to place the number of engineers alone as in the neighborhood of one hundred thousand—one for each four hundred of our working population. If such a body of men—so trained and so animated—speak as a unit after due consideration, they will receive attention. If they act as a unit, they will accomplish.

There will be leaders in the work—men of extended accomplishment and commanding personality—and through them will come that coordination and direction of the work of the individual which makes for the maximum of performance; but without the work of the individual they can do nothing. Through association of the individual we can develop the conclusions upon which to predicate action and again through association we may best assure that action.

As I come into contact with the work that has been done in the Institute by the men who have given and are giving freely of themselves in every capacity to serve it and through it their fellows, I cannot but be impressed with the extent to which this tradition of service has made itself evident in them.

To it must be credited that common bond of which our gathering here tonight is but a visible evidence and only through its continuance may we look forward to an indefinite succession of similar assemblies, and the adequate performance of the duties which devolve upon us.

A. I. E. E. DIRECTORS MEETING FEBRUARY 16, 1921

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Wednesday, February 16, 1921, at 3:00 p. m.

There were present: President A. W. Berresford, Milwaukee; Past President Calvert Townley, New York; Vice-Presidents Charles S. Ruffner, New York, L. T. Robinson, C. S. McDowell, Schenectady, E. H. Martindale, Cleveland; Managers Walter A. Hall, Boston, Wm. A. Del Mar, W. I. Slichter, L. E. Imlay, E. B. Craft, New York, Wilfred Sykes, F. F. Fowle, Chicago, G. Faccioli, Pittsfield, Frank D. Newbury, Pittsburgh; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

The Board ratified the approval by the Finance Committee of monthly bills amounting to $16,640.59.

Reports were presented of meetings of the Board of Examiners held February 7 and 11, 1921; and the actions taken on applications at those meetings were approved. Upon the recommendation of the Board of Examiners the following action

was taken upon pending applications: 229 Students were ordered enrolled; 277 applicants were elected to the grade of Associate; 9 applicants were elected to the grade of Member; 16 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

Chairman Slichter of the Meetings and Papers Committee presented a progress report of the March 11th (New York), April 16th (Pittsburgh), and May 20th (Annual Business) meetings, which had already been approved by the Board. Details may be found elsewhere in this issue.

A petition was granted for authority to organize an Institute Section at Omaha, Nebraska.

Authority was granted for the establishment of a Student Branch at Cooper Union, New York City.

Announcement was made of the appointment by the President as required by the constitution, of the Tellers Committee to canvass and report upon the nomination and election ballots in connection with the 1921 election of Institute officers.

President Berresford informed the Board regarding an invitation which had been extended to the Institute by the American Engineering Standards Committee, under date of January 24, to appoint a representative and an alternate on a General Correlating Committee for Mining Standardization, advising that he had appointed Mr. F. L. Stone, of the General Electric Company, Schenectady, as the Institute's representative. Mr. Stone is a member of the Institute's Mines Committee, the Chairman of which, Mr. Graham Bright, has already been appointed to the Correlating Committee by the A. I. M. E. Mr. Berresford stated that an alternate would be appointed later.

In addition to these actions many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

THE INSTITUTION OF ENGINEERS (INDIA)

Communications received recently at A. I. E. E. Headquarters from Mr. Hugh W. Brady, Secretary, The Institution of Engineers (India), Clive Buildings, Calcutta, announce the inaugural meeting of that Institution in Calcutta, February 23-25, 1921, including the annual general meeting, technical sessions, visits to engineering enterprises, social events, and so forth.

Sir Rajendra Nath Moekerjee, K. C. I. E., Hon. Life Member I. Mech. E., has succeeded Sir Thomas Ward as President of the Institution.

JOHN FRITZ GOLD MEDAL

Awarded to Sir Robert Hadfield of London

The John Fritz Medal Board of Award at its annual meeting on January 21, awarded its gold medal and diploma to Sir Robert Hadfield of London for the invention of manganese steel.

Manganese steel was first described in a paper read by Sir Robert Hadfield before the International Engineering Congress in 1893. For uses in which toughness combined with great strength is demanded, manganese steel is invaluable. It is also non-magnetic. Its applications, therefore, have been manifold and various; it is used in enormous quantities the world around.

During the war, thousands of soldiers' lives were saved by manganese steel, for it was found to be the most effective material for helmets and body armor. Nine million Hadfield manganese steel helmets were used by the English American and Belgian armies, and this type was replacing the French type in the French armies when the war ended. These manganese steel helmets were vastly superior to the German helmet, which were made of nickel-chromium steel and were twelve ounces heavier.

Robert A. Hadfield was born in 1859. He has made many inventions in connections with the steel industry and has been a prolific technical writer, receiving many honors for his achievements. Besides manganese steel, he invented a magnetic steel of high permeability, that is a steel which is especially suitable for use in generators and motors. It was long thought that the purer the iron the better would be its qualities for use in generators and motors, but Hadfield showed that a steel containing 2½ to 4 per cent of silicon after a double heat treatment, was far superior to the purest obtainable iron. He is a member of many scientific societies in England and other countries, among them the American Institute of Mining and Metallurgical Engineers and the American Institute of Electrical Engineers. He has been an energetic promoter of the scientific societies of Great Britain and has done much to increase their usefulness. Although so distant from New York, he is one of the greatest users by mail of Engineering Societies Library.

The John Fritz Medal was established in 1902 to honor John Fritz, the great iron master of Bethlehem, Pennsylvania, to whom the first medal was awarded in that year on his eightieth birthday. In 1905, the medal was awarded to Lord Kelvin for his work in cable telegraphy and other scientific attainments. On the list of recipients of the medal are many distinguished namse.

In 1906 and succeeding years, it has been bestowed upon:

George Westinghouse for the invention of the air brake;

Alexander Graham Bell for the telephone;

Thomas A. Edison for numerous electrical and other inventions;

Charles T. Porter for advancing the knowledge of steam engineering;

Alfred Noble for notable achievements as a Civil Engineer;

Sir William H. White for notable achievements in Naval Architecture;

Robert W. Hunt for contributions to the development of the Bessemer process of making steel;

Professor John E. Sweet for advancement in machine design and development of the high-speed steam engine;

Dr. James Douglas for achievements in Mining Metallurgy, Education and Industrial Welfare;

Dr. Elihu Thomson for electrical inventions and scientific research;

Dr. Henry M. Howe for investigations in metallography of iron and steel;

J. Waldo Smith, the Chief Engineer of the Catskill Aqueduct;

General George W. Goethals, the builder of the Panama Canal;

Orville Wright for the development of the airplane.

The medal is awarded annually for notable scientific or industrial achievement by a board of sixteen prominent men representing the National societies of Civil, Mining, Metallurgical, Mechanical and Electrical engineers.

SCANDINAVIAN FELLOWSHIPS TO BE AWARDED

The American-Scandinavian Foundation, 25 West 45th Street, New York, will award twenty fellowships for graduate study in the Scandinavian countries, ten being in Sweden, five in Denmark and five in Norway, covering a wide variety of subjects. Application papers will be mailed on request to James Creese, Jr. at the office of the Foundation.

Candidates must have been born in the United States or in some of its possessions, must be capable of original research and must submit a definite plan of study. It is desirable that they be college graduates and speak at least one language besides English. The stipend is generally $1000, but in a few cases $1200. The period of study includes one academic year.

Application papers must be filed at the office of the Foundation before March 15th and successful candidates will be notified about April 15th.

AMERICAN ENGINEERING COUNCIL

MEETING AT SYRACUSE, N. Y. FEBRUARY 14, 1921

A business meeting of American Engineering Council was held at the hotel Onondaga, Syracuse, N. Y., on the morning and afternoon of February 14, 1921, with Herbert Hoover presiding. The most important action at the meeting was the election of L. W. Wallace as Secretary of The Federated American Engineering Societies. Mr. Wallace has already been serving as Treasurer of the Federation and as Vice-Chairman of its Committee on Industrial Waste. Upon his election as secretary the office of treasurer became vacant, and W. W. Varney of Baltimore was elected temporary treasurer.

Mr. Wallace was graduated in mechanical engineering from the Agricultural and Mechanical College of Texas in 1903. He afterward served a railroad apprenticeship and became instructor at Purdue University, then assistant professor of car and locomotive design, and finally, in 1913, head of the department of railway and industrial management, which position he held until 1917. He received the degree of M. E. from Purdue in 1912. Upon leaving the university he became assistant general manager of the Diamond Chain and Manufacturing Co., Indianapolis, Ind. At the close of the war, when the Red Cross Institute was established at Baltimore for the purpose of giving vocational training to blind soldiers, Mr. Wallace left Indianapolis to become director of the Institute and conducted the work until last January, when he was elected treasurer of The Federated American Engineering Societies. In the conduct of his many activities he had displayed breadth of vision and has been actuated by altruistic motives, characteristics which, combined with an executive experience and a deep interest in the principles of management, admirably adapt him for the work he is to undertake. In various addresses on the subject of industrial management before The American Society of Mechanical Engineers and elsewhere he has shown insight into the fundamentals underlying industrial unrest and a sympathetic appreciation of the rights as well as the responsibilities of employee and employer. This latter will be the most favorable asset to Mr. Wallace in conducting the important investigation dealing with the elimination on waste in industry which is to be undertaken by the Federation.

Various business matters relating to the work of the Federated American Engineering Societies were transacted at the meeting. The Council strongly endorsed the model bill on registration of engineers previously prepared by Engineering Council. It also approved legislation proposed in connection with the Nolan Patent Bill providing for a reciprocal arrangement with foreign countries to remove discrimination against patents in foreign countries held by American inventors. Announcement was made of the membership of the Federation's Committee on Elimination of Waste in Industry, appointed in accordance with the suggestion of Herbert Hoover that the subject be taken up as one of the major activities of the Federation. The personnel of the Committee is as follows: J. Parke Channing, Chairman; L. W. Wallace, Vice Chairman; Robert B. Wolf, Chas. E. Knoeppel, Robert Linton, J. H. Williams, Fred. J. Miller, L. P. Alford, Ira N. Hollis, George D. Babcock, Morris L. Cooke, E. E. Hunt, Harrington Emerson, H. R. V. Scheel, and F. G. Coburn. It was voted to recommend to President-Elect Harding that an engineer be appointed on the Interstate Commerce Commission. Before adjournment the next place of meeting of the Council was announced to be Philadelphia.

EXTRACTS FROM ADDRESS OF HERBERT HOOVER PRESIDENT AMERICAN ENGINEERING COUNCIL

The Federation of Engineering Societies has been brought about solely that we might secure for public service the collective thought and influence of 100,000 to 200,000 of our professional engineers. This great body of men in administrative and technical service penetrates every industrial avenue and thus possesses a unique understanding of many of our intricate economic problems and an influence in their solution not equalled by any other part of the community. Wanting nothing from the public either individually or as a group, it is indeed in a position of disinterested service. This Federation has initiated services to the public in many directions.

I propose to deal with only one measure of this service today. Your Council has organized a preliminary survey of some of the weaknesses in our production system. This survey will attempt to visualize the nation as a single industrial organism and to examine its efficiency towards its only real objective,—the maximum production. In a general way this inquiry will bear upon the whole question of deficiency in production—industrial waste in a broad sense.

The waste in our production is measured by the unemployment, the lost time due to labor conflict, the losses in labor turnover, the failure to secure maximum production of the individual due either to misfit or lack of interest. Beyond this again is a wide area of waste in the poor coordination of great industries, the failures in transportation, coal and power supplies which reecho daily to interrupt the steady operation of industry. There are again such other wastes due to lack of standardization, to speculation, to mismanagement, to inefficient national equipment and a hundred other causes. There is a certain proof of deficient production by comparisons of our intense results in 1918, when, with 20 per cent of our man-power withdrawn into the army, we yet produced 20 per cent more commodities than we are doing today. We are probably not producing more than 60 or 70 per cent of our capacity; that is, if we could synchronize all national effort to maximum production, we could produce 30 or 40 per cent more commodities and service. Our national machine is today doing worse than usual, as witness the 3,000,000 idle men walking our streets. One part of the human measure of this shortage in production is the lack of necessities or comforts to them and their families, and their anxieties as to the future.

No one will ever suppose that it is ever possible to bring national productivity up to the full 100, but the whole basis of national progress, of an increased standard of living, of better human relations, indeed of the advancement of civilization, depends upon the continuous improvement in productivity. While we currently assume that great advances in living standards are brought about by new and basic invention, yet in fact even a greater field of increasing standards lies in the steady elimination of these wastes. The primary duty of organized society is to enlarge the lives and increase the standards of living of all the people—not of any special class whatever. We are therefore proposing to make a preliminary examination of the volume of waste in certain industries, the proportions that lie in each field of fault. And no engineering report is worth the paper it is written upon without constructive suggestions in remedy.

The largest area of waste lies in the large periods of slack

Delivered before meeting of American Engineering Council at Syracuse, New York, February 14, 1921.

production and unemployment, due to the ebb and flow of economic tides between booms and slumps. The ideal would be steadily increasing production—an ideal of no likelihood of exact realization because of inability to ever gage the advance in growth consumption or the approach of saturation. On the other hand, there are certain possibilities of stabilization worth consideration. For instance, we can classify labor into that engaged in production and service from this equipment. Our studies of industries as a whole show that we usually expand our equipment just at the periods of maximum demand for their products instead of doing our plant expansion during periods of slack consumption. We thus make double demands on labor and we doubly increase unemployment in periods of reduced consumption. That is indeed one of the factors in our great unemployment today. Everyone knows that for our normal productivity, our transportation facilities are today inadequate. We know that we are insufficiently housed, insufficiently equipped in our public roads and our public utilities; that we need an entire revision of our power supply, that we need expansion of our waterways, and yet armies of idle men are walking the streets. The reasons why this occurs are not far to seek, in that it is at times of high productivity that capital is most easily obtained. It is then that the necessity of increased equipment most impresses men's minds and it is the high hopes of these periods that lead them into the adventure of expansion. Nor is it possible to expect that all industry could be so stabilized as to do its capital construction in periods of depression in commodity demand. Nevertheless, there are some industries that could, by cooperation of the government and cooperation amongst themselves, be led in this direction. More particularly does this apply to railways, telephones, telegraphs, power supplies and other public utilities, and to the expenditure upon our state, municipal and national public works.

Another variety of intermittent employment, and thus great waste, lies in certain industries now operating upon an unnecessarily wide seasonal fluctuation, as for instance the bituminous coal industry. This is today one of our worst functioning industries. These mines operate seasonally and erratically. They proceed from gluts to famines, from profiteering to bankruptcy. As already determined by our engineering bodies, the men who mine our coal find work only 70 per cent of their time. In other words, there are 30 per cent more equipment, 30 per cent more men, attached to this industry than are necessary if it were stabilized to continuous operation. The mining engineers have already pointed out the directions in which remedy lies, through storage, through railway rate differentials and other remedies. Through constructive action, an army of men could be released from this industry of necessity to convert some luxury into a necessity of tomorrow.

The second largest area of waste in productivity is the eternal amount of labor friction, strikes and lockouts. The varied social and economic forces involved in this problem need no repetition here. Fundamentally this is not alone a struggle for division of the results of production between capital and labor, but there is also a loss greater from strikes and lockouts in the element of purely human friction and loss outside the area of dispute on wages and hours. The growth of industry into large units has destroyed the old mutuality of interest between employee and employer. Our repetitive processes have tended to destroy the creative instinct and interest in employees; at times their efforts sink to low levels indeed. We will yet have to reorganize the whole employment relationship to find its solution. There is great promise in this field during the past two years, and the progress in this matter is one of the subjects under our inquiry.

Yet another variety of loss lies in the unnecessarily faulty distribution of our labor supply due to seasonal and to shifting demands. An adequate national employment service is indeed the first need to reduction of these wastes.

Probably the next largest fraction of waste in productivity lies in a too high degree of individualism in certain basic products and tools. In other words, a standardization of certain national utensils makes for economy in distribution, in operation and in repairs. The necessity of maximum production during the war opened a great vista of possibilities in this direction. Such standardization as car couplings, or wheels, and cars generally, represent real progress in this direction. These possibilities lie in a hundred directions. It is certain that there are a great many articles of every-day use in which the manufacturer would indeed be glad to undertake some cooperation in standardization, from which the saving in national effort would be interpreted not into millions but into billions of dollars. This does not mean that we stamp the individuality out of manufacture or invention or decoration; it means basic sizes to common and every-day things.

Another type of waste lies in our failure to advance our industrial equipment. The Superpower Survey will demonstrate the saving of 25,000,000 to 50,000,000 tons of coal annually by the electrification of our eastern power supply. The St. Lawrence Waterway Commission will demonstrate the saving of five to ten cents a bushel to the farmers of fifteen states by unlocking the lakes to ocean-going vessels. Nor will this added efficiency to our national transport injure our present systems of canals and waterways, for we have ever found that the prosperity of an industry blesses them all.

Nor do we believe it is necessary to effect these things by the government. The spirit of cooperation that has been growing in our country during the last thirty years has already solved many things; it has standardized some things and is ripe for initiative toward cooperation of a wide-spread character. The leadership of our Federal government in bringing together the forces is needed. No greater field of service exists than the stimulation of such cooperation. The first step is sane analysis of weakness and sober proposal of remedy. If the facts can be established to an intelligent people such as ours, action is certain even if it be slow. Our engineers are in unique position for this service, and it is your obligation to carry it forward.

CURRENT ENGINEERING TOPICS

BOARD OF SURVEYS AND MAPS

Under the authority of special Executive Order, the Federal Power Commission, Army Air Service and Naval Aviation have been added to the membership of the Board of Surveys and Maps and instructed to name their representatives. At a postponed meeting of the Board held on Feb. 9 the same officers were reelected for the ensuing year, namely, O. C. Merrill, Chairman, Wm. Bowie, Vice-Chairman, and C. H. Birdseye, Secretary. It was decided that committees would be partially reorganized so as to better distribute the work. The regular public meeting will be held on March 8 to which representatives from all outside organizations are invited.

RECLASSIFICATION AND COMPENSATION OF ENGINEERS IN GOVERNMENT SERVICE

The chairman of the House Committee on Reform in the Civil Service announced on February 1st that no hearings would be held on the Reclassification Bill, which means that this bill will die when Congress adjourns. The report of this committee and the bill which was drawn as a result of this report would have affected practically every engineering position in the Government and would have meant a raise in salary under the new classification.

WORK OF FEDERAL POWER COMMISSION

As a result of the hearings January 24-26, it was decided that no applications involving the prospective use of water from Niagara Falls under an amended treaty with Great Britain

will be considered by the Commission. The Commission will, however, give consideration to possibilities under additional diversion in considering proposals for the use of existing water. It was also made plain that the International Joint Commission will have to consider the proposed developments in the gorge. The principal considerations in addition to the power will be the retention of scenic features and protection against ice jams in this gorge development.

The House Committee on Interstate Commerce has reported two bills, H. R. 14469 and 15126, the first of which removes jurisdiction of the Commission over National Parks and the latter provides increased personnel and salaries for the employees of the Commission. It is contemplated that a special rule can be obtained in the House so that these bills can come up for immediate action. The Senate adopted an amendment to the Sundry Civil Bill on Feb. 5 decreasing the general appropriation of \$100,000 to \$80,000, providing a salary of only \$5,000 for the Executive Secretary and reducing salaries of present employees beyond what they now are receiving which means that the work of the Commission will be seriously curtailed for the coming year. This amendment can probably be blocked by the House conferees, especially if H. R. 15126, explained above, is passed by the House.

As a result of hearings before the Commission on Februay 10 and 11, a revision of Regulations 11 to 17 has been made embodying many of the suggestions made to the Commission. These regulations are as follows:

11. General considerations affecting approval
12. Project work
13. Lands reserved or classified as power sites
14. Annual charges
15. Benefits from headwater improvements
16. Depreciation reserve
17. Expropriation and allocation of earnings

It is expected that the revised copies will be ready for distribution soon. The Commission is also to be asked to give final authority to authorize formal issue of licenses to 12 applicants whose projects have been advertised. The Commission has issued its report recommending a start on this development. The complete report has been printed as a Senate document. Over 175 applications for licenses or permits have been received to date.

AMERICAN ENGINEERING STANDARDS COMMITTEE

CEMENT SPECIFICATIONS MADE UNIFORM

Complete agreement has been reached on Specifications and Tests for Portland Cement. so there is now one specification covering both commercial and governmental use. Only minor changes were necessary in order to eliminate slight but long-standing discrepancies which had existed between the industrial specifications and those of the Government.

The revised specifications, which were agreed upon by Committee C-1 of the American Society for Testing Materials and the government Departmental Committee on Cement, have received the approval of the American Engineering Standards Committee.

Copies may be obtained from the American Engineering Standards Committee, 29 West 39th Street, New York, or from the American Society for Testing Materials. The price is 25 cents.

"NATIONAL ELECTRICAL CODE" SUBMITTED FOR APPROVAL

The National Fire Protection Association has submitted its "Regulations of the National Board of Fire Underwriters for Electric Wiring and Apparatus," edition of 1920, frequently referred to as the "National Electric Code," to the American Engineering Standards Committee for approval as an "American Standard."

This Code is submitted in accordance with the special provision in the procedure of the Committee, under which important codes in existence prior to 1920 may be approved without going through the regular process followed in new work.

The Committee would be very glad to learn from those interested, of the extent to which they make use of this Code and to receive any other information regarding the Code in meeting the needs of the industry.

Copies of the Code may be obtained from the National Board of Fire Underwriters, 76 William Street, New York, or from the American Engineering Standards Committee.

SPECIFICATIONS SUBMITTED FOR APPROVAL

The American Society for Testing Materials has submitted the following specifications to the American Engineering Standards Committee for approval as "Tentative American Standards":

Standard Test for Toughness of Rock.

Standard Method for Distillation of Bituminous Materials Suitable for Road Treatment.

Standard Method for Sampling Coal.

The specifications are submitted in accordance with the special provision in the procedure of the Committee, under which important standards in existence prior to 1920 may be approved without going through the regular process followed in new work.

The Committee would be very glad to learn from those interested of the extent to which they make use of these specifications, and to receive any other information regarding the specifications in meeting the needs of the industry.

These specifications may be found in the 1918 volume of A. S. T. M. Standards. Copies may also be obtained from the American Engineering Standards Committee.

BUREAU OF MINES SPECIFICATIONS BEFORE A. E. S. C.

The Bureau of Mines has brought three of its publications to the attention of the American Engineering Standards Committee for consideration as "Tentative American Standards." They are:

Permissible Portable Electric Mine Lamps (Schedule 6A)

Specification for Storage Battery Locomotives (Schedule 15)

Suggested Safety Rules for Installing and Using Electric Equipment in Bituminous Coal Mines (Technical Paper 138)

They are submitted for consideration in accordance with the special provision in the procedure of the Committee, under which important specifications in existence prior to 1920 may be approved without going through the regular process followed in new work.

The Committee would be very glad to learn from those interested of the extent to which they make use of these specifications and rules, and to receive any other information regarding them in meeting the needs of the industry.

Copies of these publications may be obtained from the Bureau of Mines, Washington, D. C., or from the American Engineering Standards Committee.

STANDARDIZATION OF INSULATED WIRES AND CABLES

A conference on the standardization of insulated wires and cables was held in New York, February 2d. The conference which was called by the American Engineering Standards Committee at the instance of the American Railway Engineering Association, was attended by representatives of fourteen national organizations.

After a thorough discussion of the many considerations involved, it was unanimously decided that, "The unification of specifications for wires and cables for other than telephone and telegraph use should be undertaken under one general plan, covering substantially all the more important uses." It was agreed that work on the following should be included:

Conductor, quality, stranding, sizes.
Rubber insulation.
Varnished cloth insulation.
Impregnated paper insulation.
Magnet wire (including enamel, cotton and silk insulation).
Fibrous coverings (including asbestos).
Sheaths.
Armor.
Standard make-ups.

Nearly a dozen organizations now have important publications on the subject, and it was agreed that the proposed work should be a unification of the specifications and standards already in existence, rather than an attempt to formulate entirely new standards, except in fields not already covered.

It was the consensus of opinion that, in order to promote export trade, it would be desirable to have all the American wire and cable standards assembled in a single book. This form of publication, while giving due credit to the participating organizations, would appear to foreign wire and cable purchasers as a complete book of American Standards, rather than as the standards of societies comparatively unkown abroad. This has been done in a very thorough way by the Germans and to a considerable extent by the British, thus placing Americans at a decided disadvantage in foreign trade. It was agreed that if such a book were prepared and given proper publicity in foreign countries, it would remove one of the greatest difficulties under which American manufacturers are now laboring in developing export trade.

The proposed work will be carried out under the auspices and rules of procedure of the American Engineering Standards Committee.

RECENT FOREIGN ENGINEERING STANDARDS

Copies of the following engineering standards, issued in 1920 by foreign national standardizing bodies, are on file with the American Engineering Standards Committee.

British Engineering Standards Association
- No. 1 Rolled Steel Section for Structural Purposes, Lists of
- No. 12 Portland Cement, Specifications for
- No. 94 Watertight Glands for Electric Cables, Specification for
- No. 97 Watertight Fittings for Incandescent Electric Lamps, Specifications for
- No. 100 Body Spaces and Frame Ends for Chassis for Private Automobiles, Dimensions for
- No. 106 Electrically Heated Cooking Range, Specification for
- No. 122 Milling Cutters and Reamers, Standards for
- No. 131 Notched Bar Test Pieces, Forms of

Canadian Engineering Standards Association
- No. 1 Steel Railway Bridges, Standard Specification for

Association Belge de Standardisation (Belgium)
- No. 1 Construction of Metal Framework, Rules for
- No. 2 Construction of Metal Tanks, Rules for
- No. 3 Construction of Coverings and Partitions of Corrugated Galvanized Sheet-iron, Rules for
- No. 4 Shafts and Transmission Pulleys, Standardization of
- No. 5 Construction of Metal Bridges, Rules for

Hoofdcommissie voor de Normalisatie in Nederland (Holland)
- N 19 Compression Couplings
- N 20 Flange Couplings
- N 29 Loose Collars for General Construction
- N 30 Loose Collars for Millgearing

Normenausschuss der Deutschen Industrie (Germany)
- DIN 187 Angle Arm for fixed Bearings for Transmission Shafting
- DIN 475 Widths of Spanner Jaws

Commission de Normalisation du VSM (Switzerland)
- VSM 10300 to VSM 10307 Technical Drawings—Oblique Script; Size of Letters; Graphic Presentation of Screw; Cross-Sections
- VSM 12050 Screw-Whitworth Threads: General Data
- VSM 33900 to VSM 33914 "Sulzer" Attachment for Milling Cutters

Sveriges Maskinindustriförening (Sweden)
- SMS 1 Size for Standard Sheet
- SMS 2 Metric Screw Thread System
- SMS 3 Whitworth Screw Thread System
- SMS 5 Hexagonal Nuts-Type B6M-BSW Screw Thread System
- SMS 7 Finished Hexagonal Screws-Type B6S-BSW Screw Thread System
- SMS 8 Series of Standard Diameters

Photostatic copies of these standards can be furnished at a nominal cost, or the copies on file may be consulted at the offices of the American Engineering Standards Committee.

INSTITUTE OF RADIO ENGINEERS

OFFICERS AND BOARD OF DIRECTORS FOR YEAR 1921

The annual election of officers recently held by the Institute of Radio Engineers resulted in the election of E. F. W. Alexanderson, president; Fulton Cutting, vice-president; A. N. Goldsmith, secretary, and W. F. Hubley, treasurer. The Board of Direction of the Institute is made up of the officers and the following managers: E. H. Armstrong, W. H. G. Bullard, E. H. Colpitts, L. Espenscheid, J. V. L. Hogan, L. R. Krumm, R. H. Marriott, Donald McNicol and George O. Squier.

NATIONAL RESEARCH COUNCIL

AN INFORMATIONAL SERVICE CONCERNED WITH METALS AND ALLOYS

An Alloys Research Association is being formed with an Alloys Informational Service as the first step. This is to be cooperative on the part of those interested in metals and their alloys. An Advisory Committee, composed of 17 prominent technical men, was formed sometime ago and this committee has evolved a plan, in conference with the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, whereby a service of a different scope from any now existing can be carried on for the benefit of the alloy men. It has been felt that it is time to broaden the sources of knowledge and to have a cooperative service that will critically and analytically digest the great mass of data that has been accumulated, but is now largely inaccessible. Technical men have not the time to spend in searching even all of the current literature. It is now planned to create a special scientific staff composed of a director and a corps of assistants who will give all their time to rendering a service of two distinct types—(1)Current Informational Service—supplying information as to new results; (2) Reference Service—supplying as fully and promptly as practicable all existing information relating to any phase of a subject. The Board of Managers, appointed by three of the divisions of the National Research Council, is constituted of Mr. Alfred D. Flinn, Secretary of Engineering Foundation, Dr. R. B. Moore of the Bureau of Mines, and Mr. W. M. Corse, Secretary of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers.

The Research Extension Division of the National Research Council, Washington, D. C., which is aiding in the organization, will be glad to supply fuller details about this service.

MEETING OF DIVISION OF ENGINEERING

Some benefits to industry resulting from research scientifically conducted were interestingly stated by Dr. Charles L. Reese, Chemical Director, E. I. Du Pont de Nemours & Company,

and Mr. A. J. Wadhams, General Superintendent, International Nickel Company, in addresses before the Division of Engineering of the National Research Council, February 4, at the Engineers Club, New York.

Dr. Reese emphasized the value to industries of organized research in particular. Some research projects are not immediately productive of financially profitable returns, others yield great savings or large profits immediately. If research be properly organized, or conducted on a cooperative basis by one great industry or a group of industries, a winning average, from the accountant's method of keeping score, is much more likely to be made. But organization and cooperation must be so conducted that the individual research worker feels no restraint. Mr. Wadhams told of the hurdles research had to take successfully in order to become established in old industrial plants. Three groups particularly required "converting," the directors, the shop superintendents and the foremen. Success depends largely upon the human qualities of the research personnel and their ability sincerely to recognize the value of the knowledge gained by the practical man in his experience, as well as the knowledge of the laboratory.

Galen H. Clevenger, Consulting Metallurgist, U. S. Smelting and Refining Company, Boston, presided at the meeting of the Division of Engineering, at which there were present twenty-two members and guests, men of high standing as research specialists or executives in leading industries. The Division's work is directed toward stimulation of research in the industries, and bringing about cooperation in the acquisition of new scientific knowledge and its dissemination among engineers and managers of our industries. The Division is supported by the National Research Council and by Engineering Foundation, representing the National Societies of Civil, Mining, Metallurgical, Mechanical and Electrical engineers.

PERSONAL MENTION

RALPH D. MERSHON, consulting electrical and mechanical engineer, announces that his New York office is removed to 143 Liberty Street.

ALLEN E. RANSOM, formerly with the Westinghouse Electric & Mfg. Co., has become Superintendent of the Olympia Light & Power Co., Olympia, Wash.

H. B. BASSETT has been placed in charge of a Chicago office of the Acme Wire Company, opened at Room 1105, Monadnock Block, 53 West Jackson Boulevard, Chicago.

H. R. SEARING, who was located with the Aviation General Supply Depot, Fairfield, Ohio, is now connected with the United Elec. Lt. & Pr. Co., 130 East 15th St., New York.

GEORGE E. SANFORD has been elected president of the American Society of Safety Engineers. Mr. Sanford is with the General Electric Company, West Lynn, Mass.

FREDERICK T. LOHR, who has been with the New York Pyritos Co., Inc., at Gouverneur, N. Y., is now electrical engineer with the Soper-Mitchell Coal Co., Morgantown, West Va.

W. J. DAVIS of the General Electric Co., who has been Pacific Coast engineer at San Francisco, is now located in the Ry. and Traction Engineering Department at Schenectady, N. Y.

FRANK CONRAD of the Westinghouse Electric and Manufacturing Company, has been appointed assistant chief engineer. He has been located with that company for nearly thirty years.

FRED G. SINGER has accepted a position as instructor in Electrical Engineering at the University of Wisconsin. Mr. Singer has been a student engineer with the General Electric Company.

J. B. PRICE has discontinued his connection as New York District Manager of the Refinite Co., Inc., and will be associated from now on with the American Water Softener Co. of Philadephia.

CARROLL H. SHAW is now in the Engineering Distribution & Installation Department of the New York Edison Company. He has been located for the past year with Jackson & Moreland, Engineers, Boston.

WILLIAM A. WEBER, formerly with the Century Electric Co., Philadelphia, has become connected with the Western Electric Co., Chicago, where he will be in the central office engineering division, Hawthorne Plant.

A. H. GRISWOLD, who has been located in San Francisco with the Pacific Telephone & Telegraph Company, has been appointed assistant chief engineer of the International Western Electric Company, Inc., in New York.

HARRY W. OSGOOD of the Bethlehem Shipbuilding Corporation, has been appointed plant engineer of the Fore River works, at Quincy, Mass. He has been with the Bethlehem company since the fall of 1919.

JOSEPH H. LIBBEY, formerly electrical engineer with the Eastern Massachusetts Street Railway Company, has joined the organization of H. M. Haven & Wm. W. Crosby, engineers and architects, with offices at 40 Court Street, Boston.

W. R. WHITNEY, director of the research laboratory, General Electric Company, Schenectady, N. Y., was awarded the Perkin medal on January 14 by the American Section of the Society of Chemical Industry. Dr. Whitney received this honor for his many inventions in chemistry.

WILLIAM EVES, 3rd, whose former address was with the American Vulcanized Fibre Co., Wilmington, Del., is at present working in Germany under the American Food Administration, with the American Friends Service Committee. He expects to return to the U. S. this summer.

CHARLES F. VAN WICKLE has completed his work in designing electrical machinery with the Silk Producers Corporation, Hackensack, N. J., where he has been since April, 1920, and will return to his old work, telegraph engineering. His present address is 573 West 191st St., New York City.

H. C. DEFFENBAUGH has resumed his work as engineer and assistant to the secretary with the Empire State Gas and Electric Association. He was away last year on work in connection with a survey of the water-power possibilities of New York State under the direction of Col. William Barclay Parsons.

ALBERT U. BRANDT, formerly superintendent in the Alameda County District, Pacific Gas & Electric Company, has become electrical engineer of the San Francisco division of that company, and will have charge of the operation and maintenance of the electrical properties and steam generating stations in San Francisco.

J. P. JOLLYMAN of the Pacific Gas & Electric Company, has been promoted to the position of chief of the division of hydroelectric and transmission engineering, in charge of all the engineering work relating to hydroelectric stations, substations

and communication and transmission lines. Mr. Jollyman is chairman of the San Francisco Section of the Institute.

G. M. Cameron is located with the firm of Mayer, Valentine & Cameron, consulting engineers, at 621 Bangor Building, Cleveland. This firm has been in business for about a year and is becoming established, having made plans and specifications for and superintended the installation of such systems as heating, sanitation, illuminating, power, etc. in a number of buildings during the year.

Herbert Laws Webb, formerly connected with telephone work in America, has resumed practise as a consulting telephone expert in London, and took a prominent part in the fierce controversy over telephone rates and methods which has raged in England since the beginning of the year. Colonel Webb served on the Staff of the Royal Flying Corps and of the Royal Air Force during the war, and retired with the rank of Lieutenant-Colonel in 1919. He has traveled extensively in Europe, investigating the telephone business in all the principal countries, and was responsible for starting the first city telephone system in Turkey.

OBITUARY

Donald Bowman of the Commonwealth Edison Company, died January 18, 1921, after an illness of several months. Born September 18, 1881, at Converse, Ind., Mr. Bowman attended school at Marion, Ind., and later took the Electrical Engineering course at the Massachusetts Institute of Technology, from which he was graduated in 1908. He entered the service of the Commonwealth Edison Company during the summer vacation of 1907, and returned there upon his graduation from M. I. T., remaining until last October, when his health caused him to be temporarily relieved from duty. Mr. Bowman was a Member of the Institute, also of the W. S. of E., the Electric Club and the Edison Club.

George La Rue Thompson of the General Electric Company, died on January 3, 1921. Mr. Thompson was born in Corning, N. Y., June 21, 1864, and spent his younger days at Fonda and Elmira, N. Y. In 1882 he started with the New York and Pennsylvania Telephone and Telegraph Co., as manager of exchanges in several counties. He left this company in 1886 to accept a position with the Thomson-Houston Electric Company in Boston, now the General Electric Company. He remained with the General Electric Company ever since, being connected with the Atlanta, Ga., office for awhile, and since 1906 with the Philadelphia office, where he was located at the time of his death as special agent for the company. Mr. Thompson joined the Institute in 1905.

UNITED ENGINEERING SOCIETY

EXTRACTS FROM THE PRESIDENT'S REPORT FOR THE YEAR 1920

Notwithstanding the continued high cost of services and supplies, during the year 1920, the Society has fully administered its property and functions; but at the close, the accounts show that in order to pay for several permanent improvements, make changes in investments for the greater security of several funds, and meet the necessities of the Library, it was necessary to borrow from the uninvested portion of the Depreciation and Renewal Fund.

Although a number of important changes in the occupation of offices by Associate Societies had of necessity to be made, the entire building was fully occupied throughout the year, and a number of applications for space had to be refused.

The building has been most carefully maintained and some deferred maintenance carried out, so that its present condition is generally better than at any time during the last few years.

Recommendations made by the Independence Bureau, employed by the Board, for improving the fire safety of the structure and its occupants have for the most part been effected, and a further report just received states that both structural and housekeeping conditions are excellent.

The membership of the four Founder Societies at the end of the year was 44,655, and of the Associated Societies 22,609, so that a total of 67,264 engineers have headquarters in our building. Other technical societies holding meetings in the building have a large aggregate membership in addition.

On Sunday, April 25, an impressive memorial service for Andrew Carnegie was held in the auditorium under the joint auspices of the Authors Club, New York Public Library, Oratorio Society, Saint Andrews Society and United Engineering Society, at which the orators were Hon. Elihu Root and Hon. John H. Finley.

A Committee on Memorials and Entrance Hall has been studying the placing of war and other memorials in the Engineering Societies Building, the furnishing of the Entrance Hall to make it more usable and attractive, and the establishment on the ground floor of a general information bureau to serve the various societies and their visiting members.

There has also been a revision of the rates charged for the use of the Auditorium and Assembly Rooms, which had not previously borne an adequate share of the general overhead expense; the new rates are still materially lower than those charged for other halls in the vicinity.

Engineering Societies Library

The Engineering Societies Library has continued its steady progress in size and service under the direction of Harrison W. Craver. The Library contains 150,000 books, pamphlets and maps, and is valued at $311,000. Good progress has been made in the recataloging and re-arranging of the books; for this work special appropriations have been continued by the Founder Societies, and during the year $13,422.50 were expended for the purpose.

The income and expenses of the Library during 1920 were as follows:

Debit balance (temporarily advanced by U. E. S.) at end of 1919	$2,602.36
Contributions by four Founder Societies $4000 each	16,000.00
Library Endowment income	5,027.63
Transfer from Library Service Bureau surplus in November	2,000.00
Income from Douglas Fund of A. I. M. E.	5,497.60
Total	$25,922.87
The expenses were	29,114.79
Difference (deficit)	3,181.92
Library Service Bureau	
Actual cash receipts	$22,797.15
Actual cash disbursements for the Service	22,086.88
Surplus applicable to the general overhead of the Bureau	710.27

The business transacted by the Library Service Bureau has increased from $2,410.80 in 1915, to $8,814.93 in 1918, and $22,797.15 in 1920. Efforts are now being exerted to make this valuable service better known throughout the profession. The service rendered by this department of the Library has, during the past year, extended its usefulness to clients in all but four of the states and territories, as well as in 26 foreign countries.

Engineering Council

Engineering Council continued its activities on substantially the same lines as in 1919, retaining and operating its offices in both New York and Washington.

In April, the American Railway Engineering Association

became the sixth member of Council on invitation from United Engineering Society.

An Organizing Conference held on June 3 and 4 in Washington, attended by delegates of many technical societies, led to the establishment of the Federated American Engineering Societies, acting through the American Engineering Council, which held its first meeting in November. The creation of this larger Council with ampler resources, of which three of the Founder Societies became charter members, indicated clearly that it would be unnecessary to continue Engineering Council. At the request, therefore, of Engineering Council and with the consent of the Founder and other societies interested, United Engineering Society by amendment of its by-laws, terminated Engineering Council on December 31, 1920, when the Washington office was taken over by the American Engineering Council, which will establish its headquarters in that city.

Council's financial condition may be summarized as follows:

Resources available for 1920	$31,157.03
Expenditures for 1920	24,842.84
Cash balance December 31, 1920	6,314.19
Other good assets	2,962.84
Total assets	9,277.03
Estimated expenses yet to be met	150.00
Probable balance	$9,127.03

This balance when finally determined will be applicable to the reduction of any obligations which the Board of Trustees may consider to be outstanding.

Engineering Foundation

Engineering Foundation continued its close relations with National Research Council and its contributions to the support of the Division of Engineering. Plans for increasing the endowment were developed by its Chairman, Mr. Charles F. Rand, during the year and a number of persons have been approached and indicate interest. Mr. Ambrose Swasey, in October generously added $200,000 to his previous large gifts, making the total endowment fund $502,834.80. No other gifts have been received, although one friend has offered to give $50,000 if nine others would give equal amounts. The annual income is now at the rate of $25,000. The accumulated unexpended balance on December 31, 1920 was $16,091.76. Important research projects have been assisted, both directly and cooperatively with the Research Council. The field of possible usefulness has been much increased by the most recent addition to the funds.

Further details of the activities of Engineering Societies Library, Engineering Foundation and Engineering Council are given in their several annual reports.

The affairs of United Engineering Society are in a satisfactory condition.

Very respectfully,
J. Vipond Davies
President.

EXTRACTS FROM REPORT OF TREASURER FOR CALENDAR YEAR 1920

Finances

The *Real Estate Account* now includes the following items:

Land	$540,000.00
Building	1,360,183.15
Equipment	33,171.16
Founder Societies Preliminary Expenses	24,000.00
	$1,957,354.31

The *Gross Operating Expenses* for the year 1920 were $77,486.38, as compared with $67,648.14 for the year 1919, an increase of $9,838.24.

The funds available for the *Library Board*, and spent under its direction during the year, amounted to $37,394.88. In addition U. E. S. advanced $5,142.41.

The funds available for *Engineering Council*, and spent under its direction during the year, amounted to $31,157.03, of which $6,314.19 remain unexpended.

The *General Reserve Fund* of $10,000 created by the Board of Trustees at a meeting held November 18, 1914 to be available to take care of unforeseen fluctuations of income and outlay, has been preserved intact, there arising no calls on this fund during the year 1920.

The *Depreciation and Renewal Fund* at the beginning of the year 1920 amounted to $100,199.00. During the year this fund was increased by the sum of $4,016.16 for interest earned by the investments for this fund, and was decreased by $818.75, due to difference in changing investments, making the total December 31, 1920, $103,396.41.

In accordance with the authorization of the Board of Trustees $5,000.00 corporate stock of the City of New York, Water Supply Bonds, due 1962 were sold on Feb. 9 at $4,600.00 and $5,000.00 corporate stock of the City of New York, Registered Bonds, due 1960, on March 8 at $4,587.50 and reinvestment made in $10,500.00 U. S. Second Liberty Loan, due 1942, bought at $9,469.00.

The following summary shows the amounts of the funds held by U. E. S. as of Dec. 31, 1920.

Depreciation and Renewal Fund December 31, 1919	$100,199.00
Interest on invested funds during the year 1920	4,016.16
	$104,215.16
Loss on sale of securities 1920	818.75
Total	$103,396.41
General Reserve Fund	10,000.00
Engineering Foundation Fund	502,834.80
Library Endowment Fund	93,351.25
Total	$709,582.46

Treasurer's Receipts and Payments, Year of 1920

Receipts

Cash on hand January 1, 1920		$12,537.18
From Founder and Associate societies:		
For offices, storage, halls, telephone, & misc	86,540.65	
From societies not in building:		
For Halls	9,923.42	
" Miscellaneous	902.20	
" Library	27,858.57	
" Library Service Bureau	21,374.00	
" Library Recataloging	9,583.34	
" Engineering Council	29,383.64	
" Engineering Societies Service Bureau	12,361.40	
Interest collected on Bonds & Deposits	9,583.34	
Interest collected on Engineering Foundation Bonds	25,262.97	
Sale of Bonds	50,961.25	
From A. I. M. E.		
For Building addition	2,500.00	
		286,234.78
Grand Total		$298,771.96

Payments

To Engineering Foundation		
Income from investments, less collection charges	25,262.97	
For Bonds purchased	53,771.97	
" Building Operating Expenses	86,514.64	
" Library	29,114.79	
" Library Service Bureau	22,086.88	
" Library Recataloging	13,422.50	
" Engineering Council	24,842.84	
" A. S. M. E. Notes	5,000.00	
" A. S. M. E. Interest on Notes	337.50	
" General Funds, Interest on Investment	360.00	
" Collect charge and exchanges	414.04	
" Engineering Societies Service Bureau	12,431.66	
" Permanent improvement charged to capital	10,183.15	
		283,742.94
Cash balance December 31, 1920.		15,029.02
		$298,771.96

Assets and Liabilities December 31, 1920

Assets

Real Estate	$2,957,354.31	
Investments—Foundation	502,834.80	
Library	93,043.75	
Depreciation and Renewal	100,511.42	
General Funds	7,500.00	
Cash	15,129.02	
Accrued Interest Receivable	2,586.70	
Insurance Prepaid	5,468.61	
Bills Receivable	2,500.00	
Accounts Receivable	11,274.67	
Advances to Library Board	5,142.41	
Advances to Engineering Societies Service Bureau	70.26	
		$2,703,415.95

Liabilities

Founders Equity in Property	$1,957,354.31	
Due to General Reserve Fund	10,000.00	
" " Dep. & Renewal Fund	103,396.41	
" " Eng. Foundation Fund	502,834.80	
" " Library Endowment	93,351.25	
Bills Payable	12,500.00	
Library Service Bureau unexpended balance	710.27	
Engineering Council unexpended balance	6,314.19	
Balance December 31, 1920	16,954.72	
		$2,703 415.95

Respectfully submitted,

JOSEPH STRUTHERS,

Treasurer

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

EXTRACTS FROM THE ANNUAL REPORT OF THE LIBRARY BOARD

In accordance with the provisions of By-Law 90 of the United Engineering Society, the Library Board submits the report of the Engineering Societies Library for the year 1920, this being the eighth annual report.

Service

Service to members of the Founder Societies and to other engineers shows an increase in quantity over preceding years, and also, we believe, an increased efficiency. The number of readers was 23,788, an increase of 1746 over 1919, when the attendance far exceeded any previous record. The average daily attendance was 78. The attendance after six o'clock in the evening was 4871, or 20 per cent of the total.

The number of inquiries received by telephone also increased. Statistics were not kept of this use, but it is estimated, on the basis of counts made for brief periods, that 3500 calls were answered during the year. Approximately 4500 letters of inquiry for information or copies of articles were also received and answered.

Summarizing all these methods by which the Library was used, it is seen that at least 32,000 inquiries were cared for, one-fourth of which were from engineers who could not use the Library in person. Many of these do not have ready access to reference collections, and would have great difficulty if some central bureau did not exist to supply the data that they need.

The Service Bureau has cared for all inquiries requiring special investigation and requests for translations. It has made 512 searches. In the course of these searches bibliographies were usually prepared, the number during the year being 360. The total number of bibliographies compiled by the Bureau is now 3428. Although many are on such minor subjects as to be of little general interest, the collection is a valuable reference tool.

The Bureau made 113 translations, containing 352,970 words. This is a decided increase over the 71 translations made in 1919.

During 1920 there were 2669 orders for photographs, for which 35,904 prints were made. The corresponding figures for 1919 were 2319 orders and 23,951 prints.

This mail service, by search, translation and copy, has this year reached every state and territory except four, and twenty-

eight foreign countries as well. The amount of translation was 55 per cent greater than in 1919 and the number of photographs was 50 per cent larger.

Contents

On January 1, 1920, the Library contained, ready for readers:

Volumes	115,934
Pamphlets	32,818
Maps and plans	118
Searches	3,221
Total	152,091

During the year there were added to the collection:

	Gift	*Binding*	*Purchase*	*Total*
Volumes	1081	711	545	2337
Pamphlets	1174	130		1304
Maps and plans	243		1	244
Searches				207
Total	2498	841	546	4092

The available material on December 31, after deducting books and pamphlets withdrawn for various reasons, was:

Volumes	116,551
Pamphlets	32,979
Maps and plans	362
Searches	3,428
Total	153,320

The figures given for maps and plans include only those added in the past two years, the older ones having been included as "volumes" in the general accessions.

With the exception of periodicals added by binding, the majority of the volumes added were gifts, or books sent by their publishers for review.

The most important task before your Board is that of classifying the combined collections by a uniform system and preparing a new catalog on this basis. This work was definitely commenced during 1919, as shown by our last report, and has been prosecuted as vigorously as possible during 1920.

The plan followed has proved entirely satisfactory in practise and is already showing results in increased convenience to readers, greater certainty of reference, and decreased desk attendants, although the work is still incomplete.

The work of the Catalog Department to October, 1920, was summarized in the JOURNAL for December, 1920.

FINANCIAL STATEMENT—1920

Library Maintenance

REVENUE

Appropriation for 1920	$26,000.00	
Advanced by United Engineering Society, 1919	2,502.36	
	$23,397.64	
Cash transferred from Service Bureau surplus November, 1920	2,000.00	
Total revenue		$25,397.64

EXPENDITURES

Salaries	$19,439.28	
Books and Binding	6,510.80	
Supplies and Miscellaneous Expenses	2,869.06	
Equipment	295.65	
Total expenditures		$29,114.79
Excess of expenditures over appropriation		$3,717.15

Service Bureau

REVENUE

Cash received for work done during year	$19,050.43	
Outstanding bills	3,184.07	
Total gross revenue as charged on books		$22,234.50

EXPENDITURES

Salaries	$17,040.46	
Supplies	5,046.42	
Total expenditures		$22,086.88
Balance forward 1 January, 1921		$147.62

CASH STATEMENT

Cash received	$21,374.00	
Balance forward from 1919	666.03	
Total receipts		$22,040.03
On account due depositors		131.27
Net cash receipts		$21,908.76

Recataloging

REVENUE

Founder Societies contributions	$10,000.00	
Balance forward from 1919	1,472.01	
Total receipts		$11,472.01

EXPENDITURES

Salaries		13,422.50
Advanced by United Engineering Society		$1,950.49

BOOK NOTICES (JAN. 1-31, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ADVANCED SHOP DRAWING.

By Vincent C. George. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. (Engineering education series.) 9 + 147 pp., diagrams, illus., 9 x 6 in., cloth, $1.60.

This textbook is intended for the student who has had some preliminary training in mechanical drawing and who wishes a practical knowledge of drafting as applied to various lines of engineering. Emphasis is placed on such subjects as working drawings, pictorial representation, patent office, electrical and structural drawing, piping layouts and sheet metal work.

AEROPLANE STRUCTURAL DESIGN; a Book for Designers, Draftsmen and Students.

By T. H. Jones and J. D. Frier. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. 267 pp., plates, tables, charts, diagrams, 8 x 6 in., cloth. $7.50.

Although several valuable treatises exist dealing with the problems of sustentation, stability and aerodynamics generally, the authors feel a need for a book treating the structural strength of the aeroplane, in which the loading of it and the methods of estimating its strength under load are discussed definitely and practically. The present volume treats in detail of the wings, fuselage, tail plane and elevators, landing gear and rear skid, control surfaces, flying controls and details, and is equipped with numerous tables of data needed by the designer. Complicated mathematical discussions are avoided.

AUTOMOTIVE IGNITION SYSTEMS.

By Earl I. Consoliver and Grover I. Mitchell. First edition. N. Y. and Lond., McGraw-Hill Book Company, Inc., 1920. (Engineering education series.) 10 + 269 pp., illus., diagrams, 9 x 6 in., cloth, $2.50.

This is a systematic course of study of the ignition systems used on automobiles, tractors and airplanes, for those who have to install, adjust and repair these systems in the factory and repair shop.

THE CENTENARY VOLUME OF CHARLES GRIFFIN AND COMPANY, LTD., 1820—1920.

Lond., Charles Griffin and Co., Ltd., 1920. 290 pp., ports., plates, facims., 9 x 6 in., cloth.

This volume is issued to commemorate the hundredth anniversary of the entrance of this well-known firm into the field of technical book publishing. It includes an introduction by Lord Moulton, a history of the firm, and chapters on the progress of scientific literature in various fields during the last hundred years, as marked by its publications. Among the contributors are T. Hudson Beare, Sir W. S. Abell, William Gowland and Henry Louis.

CHEMISTRY AND CIVILIZATION.

By Allerton S. Cushman. Boston, Richard G. Badger. 151 pp., ports., 8 x 6 in., cloth. $2.50.

The author of this work has attempted a brief, readable account of what chemistry has done, is doing, and hopes to do

for mankind, in which the relation of the present and the future to the past will be clearly indicated. Attention is especially given to the industrial applications of discoveries.

Coal in Great Britain.

By Walcot Gibson. Lond., Edward Arnold, 1920. 8 + 311 pp., plates, maps, illus., 9 x 6 in., cloth. $7.50. (Gift of Longmans, Green and Company.)

The present work is intended to supply mining engineers, mine owners and students with a concise account of the more important facts relating to the geology of coal generally, and to the coal fields of Great Britain in particular. The earlier chapters are reproduced, with additions, from the author's "Geology of Coal and Coal-Mining," now out of print. The rest of the book, dealing with the coal-fields, is based on thirty years' personal experience and on various publications.

Concrete Work.

By William Kendrick Hatt and Walter C. Voss. Vol. 1. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 451 pp., illus., diagrams, tables, 8 x 6 in., cloth. $4.00.

This is the first part of a two-volume manual intended to extend the scope of work now possible to the concrete worker of unguided experience by bringing him to an intelligent understanding of the scientific principles underlying his art, and by introducing him to the wider opportunities that exist for him in modern construction. The method used to present the subject is based upon the experience acquired by the Committee on Education and Special Training of the War Department, in training 130,000 soldiers in the various trades connected with military operations. The present volume of the manual contains the development of principles and information of methods of construction and standards, necessary for the construction of the definite building.

Contracts in Engineering.

By James Irwin Tucker. Second edition, seventh thousand. N. Y. and Lond., McGraw-Hill Book Co., 1920. 331 pp., 9 x 6 in., cloth. $4.00.

This book is intended as a practical course showing the contractual basis of engineering work and of business at large, and as a textbook for engineering students with no opportunity for extended study of legal principles. It aims to present those facts and rules that seem likely to be of most value to an engineer in his professional and business career and to give him substantial information upon many legal matters.

Dielectric Phenomena in High-Voltage Engineering.

By F. W. Peek, Jr. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 281 pp., plates, charts, tables, 9 x 6 in., cloth. $3.50.

It is the object of the author to give in this book the properties of gaseous, liquid and solid insulations and the methods of utilizing these properties to the best advantage in the problems of high-voltage engineering. A brief discussion of the dielectric circuit is included.

This edition has been carefully corrected and supplemented by the data that have resulted from investigations since its predecessor appeared.

Drang und Zwang; Eine Höhere Festigkeitslehre Für Ingenieure.

Von Aug. Föppl und Ludwig Föppl. München und Berlin, R. Oldenbourg, 1920. 2 vols. 10 x 7 in., paper. 72 M.

Contents: Die allgemeinen Grundlagen. Die Sätze über die Formänderungsarbeit. Die Biegungsfestigkeit der Platten. Die Scheiben. Die Schalen. Die Drehfestigkeit der Stäbe. Die Umdrehungskörper. Die Härte. Die Eigenspannungen. Die Knick und Ausweichgefahr.

The authors of these volumes discuss some of the more abstruse problems of stress and strain. The work is intended especially for engineers who are fitted, by practical experience, to follow a difficult investigation and apply its results. A knowledge of the elementary theory of the mechanics of materials is expected of the reader.

Eminent Chemists of our Time.

By Benjamin Harrow. N. Y., D. Van Nostrand Co., 1920. 16 + 248 pp., ports., plates, 8 x 6 in., cloth. $2.50.

Contents: Perkin and coal-tar dyes. Mendeléeff and the periodic law. Ramsay and the gases of the atmosphere. Richards and atomic weights. Van't Hoff and physical chemistry. Arrhenius and the theory of electrolytic dissociation. Moissan and the electric furnace. Madame Curie and radium. Victor Meyer and the rise of organic chemistry. Remsen and the rise of chemistry in America. Fischer and the chemistry of foods.

In selecting the subjects of these biographical sketches, the author has attempted to include those whose achievements have intimately affected chemical progress during the past generation or so, and thus to write a history of the chemistry of our times, centered around some of its leading figures. The book emphasizes the personal side. It is nontechnical in character, and intended for laymen as well as scientists. Brief bibliographies are included.

Exporter's Gazetteer of Foreign Markets, 1920-21.

Compiled and edited by Lloyd R. Morris. N. Y., The American Exporter. 23 + 766 pp., maps, tables, 9 x 6 in., cloth. $10.00.

This gazetteer is planned to present concisely facts about markets which have heretofore been obtainable only in scattered primary sources. The information includes the area and population of each country, the population of its principal towns, its commerce, production and industry, telegraphs, telephones and railroads, money, weights and measures, commercial language, principal shipping routes, customs tariff, consular regulations and representation, and similar matters. Maps of the principal countries are included. Foreign currencies and measurements have been converted into American equivalents.

Factory Organization and Administration.

By Hugo Diemer. Third edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 15 + 398 pp., illus. 9 x 6 in., cloth. $4.00.

This book is for officers of manufacturing corporations, works managers, superintendents, accountants, and those in charge of such activities as purchasing, stores, costs and production. The present edition has been revised to conform with the evolution of practise and standards, particularly in relation to organization, personnel problems and the functional control of production. An extensive bibliography is included.

Freileitungsbau, Ortsnetzbau.

By F. Kapper, Zweite auflage. München und Berlin, R. Oldenbourg, 1920. 8 + 365 pp., illus., diagrams, charts, tables, 9 x 6 in., paper. 40 M.

This work on the construction of aerial electric lines is a practical book, fully equipped to answer the questions of the engineer in charge of erection. Theory is reduced to small dimensions, but the information on actual methods is an ample presentation of current German practise, in minute detail. Both transmission and distribution systems are included.

The Gasoline Automobile; its Design and Construction. Vol. 1. The Gasoline Motor.

By P. M. Heldt. Sixth edition. Nyack, N. Y., P. M. Heldt, 1920. 6 + 633 pp., illus., diagrams, charts, 9 x 6 in., cloth. $6.00.

Continued development of the internal combustion engine has made necessary a further revision of this volume. The chapters on the cylinder and the crankcase and oiling system have been rewritten, and that on the piston, piston rings and piston pin revised to accord with modern practise. New material on other subjects has been added in an appendix and new plates added.

Geology of Petroleum.

By William Harvey Emmons. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 14 + 610 pp., illus., maps, 9 x 6 in., cloth.

The author has tried to present, as briefly as is practicable, a perspective of the data on the geology of petroleum, suitable for students familiar with the operation of geologic processes and the principles of stratigraphy. The book discusses the surface indications of petroleum, openings in rocks, the association of petroleum and salt water, reservoir rocks and covering strata, properties and origin of petroleum and natural gas, maps and logs, accumulation of petroleum, structural features of oil and gas reservoirs, deformation of petroliferous strata, metamorphism of petroleum, gas pressure and oil recovery, petroliferous provinces and petroleogenic epochs. Brief sketches of the important oil fields of the world are included, and numerous references given to the literature on them.

HEAT ENGINES; A TEXT-BOOK FOR ENGINEERING STUDENTS.

By David Allen Low. N. Y. and Lond., Longmans, Green and Co., 1920. 7 + 592 pp., illus., diagrams, charts, tables, 9 x 6 in., cloth. $6.50.

The author has attempted to compress into one volume of moderate dimensions sufficient material for a two-years' course in the subject, in which its theoretical and practical sides would be combined. Numerous exercises for the student are included, most of which are original.

A HISTORY OF THE CONCEPTIONS OF LIMITS AND FLUXIONS IN GREAT BRITAIN FROM NEWTON TO WOODHOUSE.

By Florian Cajori. Chic. and Lond., The Open Court Publishing Co., 1919. 8 + 299 pp., ports., 8 x 5 in., cloth. $2.00.

In this small volume, Dr. Cajori reviews the history of an important event in the history of mathematics, the conception of fluxions advanced by Newton, the controversies with Berkeley and others, and the development that the theory underwent in Great Britain during the eighteenth century.

IRRIGATION; ITS PRINCIPLES AND PRACTISE AS A BRANCH OF ENGINEERING.

By Sir Hanbury Brown. Third edition, revised. Lond Constable & Co., Ltd., N. Y., D. Van Nostrand Co., 1920. 15 + 305 pp., plates, illus., 9 x 6 in., cloth. $6.00.

The primary object of this treatise is to collect the guiding principles on which irrigation engineering is based and to furnish illustrations of their application in existing canal systems. The present edition is little changed from the preceding one, except by the addition of an appendix containing information upon changes that have taken place in the works used as illustrations.

The illustrative works are taken from Indian and Egyptian practise and are based upon the author's personal acquaintance with methods in these countries.

THE MAKING OF HERBERT HOOVER.

By Rose Wilder Lane. N. Y., The Century Co., 1920. 6 + 356 pp., port., 8 x 5 in., cloth, $2.50.

Upon the foundation of documents, letters and diaries, and information supplied by Charles K. Field, a friend and college classmate of Mr. Hoover, Mrs. Lane has prepared an informal readable account of his life. The book is unusual in method, but achieves success as an interpretation of the man.

MARGARINE.

By William Clayton. Lond. and N. Y., Longmans, Green & Co., 1920. (Monographs on industrial chemistry.) 187 pp., plates, illus., 9 x 6 in. cloth. $4.75.

This monograph is the first in any language, the author states, to give an account of the modern processes of manufacture of margarine. The chemistry of its constituents is discussed, and the methods of their analysis, as well as of the finished product, are described in detail. Chapters are devoted to butter and renovated butter, and lard compound. A chapter on nutritional chemistry deals with recent investigations on vitamines. References to the principal patents and a very full bibliography are included.

PETROLEUM REGISTER; AN ANNUAL DIRECTORY AND STATISTICAL RECORD OF THE PETROLEUM INDUSTRY IN THE UNITED STATES, CANADA AND MEXICO, 1921.

N. Y., Oil Trade Journal, Inc., 640 pp., 12 x 9 in., cloth. $10.00.

This new edition of the register has been revised and corrected up to the last months of 1920, so that it represents the latest available information. Like its predecessors it attempts to serve as a complete catalog of the industry by including both those engaged in the industry and those who manufacture and sell the materials needed by the oil trade.

The book lists the refiners, marketers and jobbers, producers, pipe lines, natural gas gasoline manufacturers and oil associations in the United States, and the more important firms in Canada and Mexico. Statistics of production, consumption and distribution are included, as are maps of the important oil producing states.

PHYSIOGRAPHY.

By Rollin D. Salisbury. Third edition, revised. N. Y., Henry Holt and Co., 1919. (American science series—advanced course.) 15 + 676 pp., plates, illus., 9 x 6 in., cloth. $4.00.

The new edition of Professor Salisbury's well-known textbook has not been changed in plan, but has been thoroughly revised throughout and rewritten in considerable part. The text is intended for students of early college grade and represents the course given in the University of Chicago. The book is distinguished by its wealth of illustration and its lists of references to other literature.

PLANTATION RUBBER AND THE TESTING OF RUBBER.

By G. Stafford Whitby. N. Y. and Lond., Longmans, Green and Co., 1920. (Monographs on industrial chemistry.) 16 + 559 pp., plates, diagrams, 9 x 6 in., cloth. $9.50.

The circumstance that the supply of raw rubber is now chiefly derived from plantations, where its preparation can be controlled technically, renders possible the development of cooperation between the producer and the manufacturer, and gives importance to the present account of the preparation of plantation rubber and of present knowledge of exact methods of testing and evaluating raw rubber. The book includes an account of investigations made by physicists into the physical properties of rubber and an extensive bibliography on the subjects covered by the volume.

PROPERTIES OF STEAM AND THERMODYNAMIC THEORY OF TURBINES.

By H. L. Callender. N. Y., Longmans, Green & Co., Lond., Edward Arnold, 1920. 531 pp., diagrams, tables, 9 x 6 in., cloth. $14.00.

This work gives a connected account of the conclusions resulting from the author's extended experimental and theoretical investigations of the problems depending primarily on the properties of steam. It is therefore intended to supplement treatises written from an engineering standpoint, by presenting the thermodynamical aspect of the problem.

The book explains the origin of the author's equations for steam, shows how well his theory has fitted with subsequent work, and how his equations and tables may best be applied to more recent developments. A considerable portion of the book deals with the thermodynamical theory of turbines, and here some new methods are introduced which the author believes will be useful to engineers. The book includes his steam tables.

RECENT ADVANCES IN ORGANIC CHEMISTRY.

By Alfred W. Stewart. Fourth edition. Lond and N. Y., Longmans, Green and Co., 1920. 359 pp., 9 x 6 in., cloth. $7.50.

The author of this work discusses the subject from a synthetic point of view, his object being "to illustrate the principles upon which modern chemistry moves—not stands—and to undermine the conservatism which exists in all but strikingly original minds." Science is to him not a mere collection of data, but rather a rapidly changing series of hypotheses by means of which we attempt to group the facts with which we are acquainted.

This edition includes a new chapter on unsolved problems and other chapters have been revised and extended.

RESEARCH AND METHODS OF ANALYSIS OF IRON AND STEEL AT A. R. M. CO.

Second edition. Middletown, O., The American Rolling Mill Co., 1920. 220 pp., illus., 9 x 6 in., cloth. $4.00.

This volume describes the methods for the magnetic, physical and microscopical testing and chemical analysis of steel used in the laboratories of the American Rolling Mill Company.

SCHMIEDE UND SCHMIEDE-TECHNIK.

By C. Oetling. Band 1. München und Berlin, R. Oldenbourg, 1920. 13 + 608 pp., illus., diagrams, 11 x 8 in., paper. 90 M.

This volume is the outgrowth of a work submitted in 1911 to the Verein deutcher Maschinen-Ingenieure in competition for a prize offered for systematic study of the value of new methods and apparatus for forging. The report has been expanded, at the request of the prize committee into an exhaustive examination of forge shop methods. The present volume, the first of two, was printed in 1914, but has only now been published.

It discusses the fuels, heating furnaces, methods of controlling heat, forging hammers and presses, shears, saws, welding, measuring instruments, cranes and conveyors. The second volume will treat of heat-treating, compressed air machinery, and of the effect of the war on labor. The volume is elaborately illustrated.

THE NEW STONE AGE.

By Harrison E. Howe. N. Y., The Century Co., 1921. (The Century Books of Useful Science.) 289 pp., plates, 8 x 5 in., cloth. $3.00.

The "new stone age" is the age of cement and concrete. The author tells in everyday language the story of cement, its history, manufacture and uses, in the hope that his book will lead to a better appreciation and more thorough understanding of it by the non-technical user, and lead him to use it with due regard not only for its excellent characteristics but for its necessary limitations.

TANKS IN THE GREAT WAR, 1914-1918.

By J. F. C. Fuller. N. Y., E. P. Dutton and Company, 1920. 24 + 321 pp., front., maps, plates, 9 x 6 in., cloth. $9.00.

This volume, by a former Chief General Staff Officer of the Tank Corps of the British Army, is a readable account of the genesis of the tank and of the part played by it in the Great War. The work of the French, German and American tank corps is covered also.

TECHNISCHER LITERATURKALENDER.

2. ausgabe, 1920. München-Berlin, R. Oldenbourg. 441 pp., front., 8 x 6 in., cloth. 40 M.

This is a "who's who" of living German writers on technical subjects, compiled by the chief librarian of the German Patent Office. About seven thousand names are included. The information includes date of birth, address, education, occupation, writings and specialty.

This edition contains a thousand names more than that of 1918, and has also an index by specialties and a list of deaths during 1918 and 1919.

THE TECHNICAL EXAMINATION OF CRUDE PETROLEUM, PETROLEUM PRODUCTS AND NATURAL GAS.

By William Allen Hamor and Fred Warde Padgett. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 9 + 591 pp., illus., tables, charts, diagrams, 9 x 6 in., cloth. $6.00.

This book is designed to present the methods in use for the examination and evaluation of natural gas, crude petroleum and oil-shale, and their important products. It includes the procedures for the physical and chemical tests which are recognized as essential, together with tables of the necessary physical and chemical data. Very full bibliographic references are given.

TELEPHONIC TRANSMISSION; THEORETICAL AND APPLIED.

By J. G. Hill. Lond. and N. Y., Longmans, Green and Co., 1920. (Manuals of telegraph and telephone engineering.) 16 + 398 pp., diagrams, 9 x 6 in., cloth. $7.00.

CONTENTS: Mathematical formulas and notes. The infinite line; Direct-current case. The equivalent circuit, Direct-current case. The loading of transmission lines and the design of artificial cables, Direct-current case. The human voice in telephony. The application of alternating currents to transmission lines. Reflection and power in telephone circuits. The constants of telephone circuits. The loading of telephone circuits, a-c. case. Methods of measurement on transmission lines, with examples of tests. The standard cable and its uses. Cost problems in telephonic transmission. Transmission formulas for lines in series, with apparatus in series and in leak. The thermionic valve as a telephonic relay.

The present volume is one of a series of treatises prepared under the editorship of Sir William Slingo, to deal comprehensively with the problems involved in the applications of electricity in telephony and telegraphy. It treats of the theory and practise of telephonic transmission, and reviews the work that has been done in Great Britain, America, France, Germany and Japan, and is the work of a specialist connected with the British Post Office.

A TEXT BOOK OF CHEMICAL ENGINEERING.

By Edward Hart. Easton, Pa., The Chemical Publishing Co., 1920. 12 + 211 pp., illus., diagrams, 9 x 6 in., cloth. (Gift of the author.)

CONTENTS: Materials. Location of works. Boilers. Prime movers. Plumbing. Crushing. Dissolving. Filtration. Tanks. Evaporation. Crystallization. Drying. Distillation. Absorption of gases. Mixing and kneading. Containers.

The contents give an indication of the scope of Dr. Hart's new book, which is based upon his courses in Lafayette College. The treatment of the subject is brief and elementary, but thoroughly practical.

THE THEORY OF MACHINES.

By Robert F. McKay. Second edition. Lond., Edward Arnold, 1920. 8 + 440 pp., diagrams, 9 x 6 in., cloth, $6.75. (Gift of Longmans, Green and Co.)

CONTENTS: Mechanics. Kinematics of machines. Dynamics of machines.

Although many books exist which cover one or two special parts of this subject, the author believes this to be the first attempt at a systematic, comprehensive review of the whole. The volume is intended for students and engineers, many exercises being included for use by the former. This edition is practically identical with the first, only minor additions and alterations having been made.

THERMO-ELECTROMOTIVE FORCE IN ELECTRIC CELLS.

By Henry S. Carhart. N. Y., D. Van Nostrand Company, 1920. 134 pp., charts, 7 x 5 in., cloth. $2.00.

This little volume is a record of the author's researches, begun many years ago with those concerning the analysis of the temperature coefficient of voltaic cells. The chapter on the electromotive force of concentration cells has especial interest, as it shows the application of the Helmholtz equation to such cells, and the relation of the Nernst equation to this formula.

A TREATISE ON REINFORCED CONCRETE.

By W. Noble Twelvetrees. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. 264 pp., plates, 8 x 6 in., cloth. $7.50.

In this volume the author has endeavored to set forth as clearly as possible the general characteristics and distinctive properties of reinforced concrete and its constituents, to discuss in a systematic manner the principles underlying the design of homogeneous members, and to show how these principles may be applied to the evolution of formulas for the design of reinforced concrete members of different classes. It is restricted to fundamental principles and presents a complete series of formulas for the principal classes of members employed in engineering and building construction.

The book is the first to employ the standard notation adopted by the Concrete Institute. This notation is given in full, with an explanatory foreword.

UNTERSUCHUNGEN UBER SCHWACHSTROMSTORUNGEN BEI EINPHASEN-WECHSELSTROMBAHNEN.

Bericht an die Königl. Schwedischen Eisenbahndirektion von der hierfür ernannten Kommission. Ins Deutsche übertragen durch Franz Kuntze. München and Berlin, R. Oldenbourg, 1920. 159 pp., illus., diagrams, charts, 11 x 8 in., paper 38 M.

In discussions of the comparative merits of direct and single-phase current systems for the electrification of trunk-line railways, one of the most common objections to the latter system is the interference with neighboring telephone lines. The present volume is a German translation of the report of a commission appointed in 1915 to study this question for the railway and telephone departments of Sweden and to prepose remedies. The report describes the investigations carried out by the commission. These included an experimental study of interference on the Kiruna-Riksgränsen railway, a series of direct measurements on the nature of interference phenomena, a theoretical investigation of the effects of conductors upon one another, suggestions for mitigating interference and reports on the theory, design, construction and action of negative boosters.

WINNING THE PUBLIC.

By S. M. Kennedy. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1920. 168 pp., port., 9 x 6 in., cloth. $2.50.

This volume includes the substance of various addresses delivered before technical and trade associations during recent years. They discuss the relations of public utilities with those whom they serve and the methods by which public confidence and good will can be secured.

DIE WECHSELSTROMBAHN-MOTOREN.

Von Max Gerstmeyer. Munchen und Berlin, R. Oldenbourg, 1919. 193 pp., illus., diagrams, 9 x 6 in., paper. 13.60 M.

Having in mind the increasing use of the single-phase motor for railway operation in Europe, the author has prepared this brief account of its principles and chief types for the use of electrical engineers who are not specially informed concerning its theory and uses.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Baltimore.—January 21, 1921, Johns Hopkins University. Joint meeting of the Baltimore Sections of the A. S. M. E. and A. I. E. E., and the Engineers Club of Baltimore. Messrs. C. W. E. Clarke and D. L. Galusha gave a lecture on the New Colfax Power Station of the Duquesne Light Company. This is one of the newest and largest steam driven electrical stations in the country and each speaker took up in detail the unusual problems met with in his respective branch of the engineering profession during its construction, illustrating the lecture by lantern slides. Attendance 125.

Boston.—January 11, 1921. Chipman Hall, Tremont Temple. Paper: "Wireless Telegraphy." Speaker: Dr. F. B. Jewett, Chief Engineer, Western Electric Company. The talk was very interesting; the most novel part was a series of animated cartoons made by the Bray Corporation of the electrons in a vacuum tube in actual operation. The electrons were represented as small white circles and the current in wires by white dashes. There were two reels of moving pictures altogether, some of the circuits being quite pretentious and showing the various events in a complete radio-phone transmitter. Attendance 250.

January 18, 1921. Lorimer Hall, Tremont Temple. Subject: "Electrical Features of the Superpower Survey." Speaker: Mr. W. S. Murray. The speaker spoke very well upon the general problem of the superpower development, and the great wastes that are at present occurring in power development which could be eliminated by the superpower plan. Attendance 200.

February 7, 1921. Boston City Club. Joint meeting of Boston Sections of A. S. M. E. and A. I. E. E., and the Boston Society of Civil Engineers. Two papers were presented as follows: "Recent Water Wheel Developments and Settings," by Mr. W. M. White, Allis Chalmers Mfg. Co., and "Design of the Steam Power Station for Hydraulic Relay" by Mr. E. B. Powell, Stone and Webster. The papers were illustrated by lantern slides. Attendance 250.

Chicago.—January 20, 1921. Joint meeting of the Chicago Section of the A. I. E. E., Railway Section of the Western Society of Engineers, and the Electrical Section of the Western Society of Engineers. Colonel Frederick Mears, Alaska Engineering Commission, gave an illustrated lecture on Alaska, which included moving pictures and slides. Colonel Mears had an exceptional story of the wonders of Alaska, its resources, problems and future. Attendance 350.

Cincinnati.—January 13, 1921. Assembly Hall, Union Gas & Electric Company. Subject: "Elevating Engineering Profession." Speaker: Mr. S. D. Heed, General Manager of the Union Gas & Electric Company. The speaker took for example the construction of Hell Gate Bridge in New York, showing many interesting slides and how this construction showed a daring engineering feat. Attendance 20.

February 10, 1921, Assembly Hall Union Gas & Electric Company. Mr. T. W. Jacobs, of the Chas. A. Schieren Company, explained the manufacturing leather belts, illustrated by a four-reel industrial film entitled "Belt Making from the Salted Hide to the Finished Product." Attendance 30.

Detroit-Ann Arbor.—January 28, 1921. Subject: "Electron Tube and Its Adaptation to the Problems of Communication." Speaker: Dr. Williams. The speaker explained, with the aid of slides and demonstrations, the production of electromagnetic waves, their transmission through space, and the receiving apparatus which is tuned to resonance with the incoming wave. The importance of resonance was clearly shown by experiments. In order to translate the oscillations picked up by a receiving station a detector of some kind is necessary. The electron tube is the best detector at the present time and its sensitiveness assures detection of very weak electromagnetic waves. This was clearly explained and demonstrated. Its ability to amplify very small currents makes it particularly useful in the transmission of speech or of telegraph signals over very long distances.

February 11, 1921. Detroit Board of Commerce. Subject: "Transformers." Speaker: Professor Parker, University of Michigan. The speaker discussed the characteristics and connections of transformers, with particular reference to open delta and star connections on three-phase circuits, also the necessary requirements in transformers for three to two-phase connections. Attendance 45.

Fort Wayne.—January 20, 1921. Mr. Walter H. Sunier of the General Electric Company, talked on the Einstein Theory of Relativity in non-mathematical language. Two reels of interesting film were also shown by the Entertainment Committee; the first reel illustrated the operating methods in the lumber industry and the second the manufacture and use of X-ray tubes. Attendance 80.

Ithaca.—January 29, 1921. Franklin Hall, Cornell University. Subject. "Some Problems in 220-kv. Transmission." Speaker: Mr. F. W. Peek, Jr., The speaker told, interestingly, yet with a minimum of technical and mathematical language, of the problems of present high-voltage transmission, and of what could be expected in the future. Attendance 170.

Kansas City.—January 25, 1921. University Club. Election of officers as follows: Chairman, Professor C. G. Shaad; Secretary, Mr. J. W. Wopat. Mr. H. C. Blackwell, General Manager of the Kansas City Power & Light Company, gave a general talk on the activities of the Institute. Attendance 19.

Lynn.— January 5, 1921. Subject: "Individualism vs. Socialism." Speaker: Mr. Charles E. Carpenter, President of the E. F. Houghton Co., Philadelphia. Attendance 150.

January 19, 1921. Subject: "Industrial Reconstruction in France and Belgium." Speaker: Mr. O. F. Allen. Mr. Allen was a Major with the 24th Engineers and was able to give first-hand information of the conditions in France and Belgium. Among the interesting things which he discussed was the Superpower System which the French are putting in and also the reconstruction of the bridges and lines of communication. Attendance 175.

February 2, 1921. Subject: "The Industrial Applications of Electrochemistry." Speaker: Professor Joseph W. Richards, of Lehigh University. Professor Richards has been indentified with the electrochemical developments at Niagara Falls, and described electrolytic and electrothermal processes. He also described some of the present day applications of these processes and showed the rapid growth that has been made in the electrical and chemical industries since the chemists and electrical engineers got together and combined their efforts. Attendance 150.

Milwaukee.—January 19, 1921, Milwaukee Athletic Club. Mr. A. W. Berresford talked to the Section members regarding the activities of the A. I. E. E. and the work of the Federated American Engineering Societies. Attendance 250.

New York.—January 28, 1921. Engineering Societies Building. Joint meeting of the New York Section of the A. I. E. E. and Metropolitan Section of the A. S. M. E. On Friday evening January 28, another extremely successful joint meeting of the New York Section of the A. I. E. E. and the Metropolitan Section of the A. S. M. E. was held in the Auditorium of the

Engineering Societies Building, New York. The attendance was well over 900.

The meeting was opened with a few remarks by W. S. Finlay, Jr., Chairman of the A. S. M. E. Section. He then introduced the presiding officer of the evening, Alfred E. Waller, of the Marine Committee of the A. I. E. E., and Chief Engineer of the Ward Leonard Company. Mr. Waller pointed particularly to the duty and ability of engineers to place the American Merchant Marine on a plane, not only where it would surpass all others in number, but also where the individual units would carry more weight of cargo per ton and log more knots per given consumption of fuel; where the ships would be safer and stauncher and the time consumed by cargo handling would be reduced to a minimum. Following his talk Mr. Waller introduced Admiral W. S. Benson, Chairman of the U. S. Shipping Board.

Admiral Benson emphasized the tremendous development which has taken place in the naval field, in vessels, mechanical appliances and personnel, since his graduation from the Naval Academy in 1877, and particularly the development of the past ten years in connection with the utilization of oil as a fuel. He was severely criticized in 1911 for having the temerity to take the battleship *Utah* from the Brooklyn Navy Yard to the Hudson River, using fuel oil alone. Admiral Benson expressed the opinion that should the engineering talent of the country devote sufficient study to the subject of motive power and auxiliaries aboard our merchant ships, there was no reason why that equipment should not be placed on a plane of efficiency equivalent to that of the Liberty Motor. The real problem is not one of personnel, but of fuel. We must insist on fuel oil; to return to coal would be suicidal. We must reduce cost of fuel and fuel consumption through the development of an internal combustion engine that will furnish power for complete electrification. Admiral Benson then cited the record of the 12,000 ton *Eclipse* steam turbo-generator, electric drive, which at last report had reached Singapore without the loss of a turn of the propeller, and with a remarkable record in reduction of fuel consumption; but he again emphasized his belief that the ultimate development would be the internal combustion engine combined with electric drive.

He then discussed the heavy charges for loading and unloading vessels, at times amounting to \$20,000 to \$25,000; pointing out the absurdity of wasting time and money to that extent when mechanical appliances would undoubtedly reduce such charges tremendously.

Chairman Waller next introduced the authors of the four papers scheduled for the evening: H. L. Hibbard, Commander C. S. McDowell, Eskil Berg and W. E. Thau. The discussion of these papers was participated in by the following: M. W. Day, J. C. Shaw, R. H. Mc Lain, G. A. Pierce, Commander Jones, W. B. Flanders, and C. O. Giroux.

Philadelphia.—January 21, 1921. Manufacturers Club of Philadelphia. Joint meeting of the Engineers Club of Philadelphia and the Philadelphia Sections of the A. S. C.E., A. S. M. E. and A. I. E. E. Opening of the afternoon technical session by Mr. Guilliaem Aertsen, President of the Engineers Club of Philadelphia. The following papers were then presented: "The Modern Hydraulic Turbine" by Mr. Frank H. Rogers, of the William Cramp & Sons Ship & Engine Building Company, Philadelphia; "The Application of a New Method of Water Measurement in the Efficiency Tests of the 37,500-h.p. Turbines of the Niagara Falls Power Company" by Mr. Norman R. Gibson, of the Niagara Falls Power Company, Niagara, Falls, N. Y.; "Speed Regulation of the Hydraulic Turbine" by Mr. Raymond D. Johnson, Consulting Engineer, New York City; "The Present Trend of Hydraulic Turbine Development" by Mr. Lewis F. Moody, of the William Cramp & Sons Ship & Engine Building Company, Philadelphia. Informal dinner at the Bellevue-Stratford Hotel. Opening of the evening session by the President of the Engineers Club and presentation of moving pictures on "Philadelphia's Waterfront from the Air." The following papers were read; "Niagara Falls Power Development and Its Products in Philadelphia" (illustrated) by Mr. John L. Harper, Vice-President and Chief Engineer, the Niagara Falls Power Company, Niagara Falls, N. Y.; "Electrical Features of Hydroelectric Power" (illustrated) by Mr. David B. Rushmore, General Electric Company, Schenectady, N. Y. Attendance 650.

Pittsburgh.—January 21, 1921. Bureau of Mines. Joint meeting of Pittsburgh Sections of A. I. M. E. and A. I. E. E. A technical session was held at 3:30 p. m., the subject being "Power Rate for Coal Mines" by Mr. H. C. Bailey, Consulting Engineer, Columbus, Ohio. At 5:00 p. m. an inspection trip was made through the buildings of the Bureau of Mines and at 6:30 p. m. a dinner was served in the cafeteria of the Bureau of Mines. The subject of the evening session was "Gathering in Coal Mines" by Mr. R. L. Kingsland, of the Consolidated Coal Co., Fairmont, W. Va. Attendance 150.

February 8, 1921, Chamber of Commerce. Subject "Some Elements of the Electron Theory of Matter." Speaker: Professor V. Karapetoff, of Cornell University. The speaker outlined some recent fundamental experiments and discussed the mathematical relationships, by means of which the size of the electron, its charge of velocity, etc., may be computed. Attendance 350.

Pittsfield.—January 20, 1921. Masonic Temple. Subject: "On the Frontiers of the Universe." Speaker: Mr. B. R. Baumgardt, Lecturer of Los Angeles and New York. Attendance 700.

February 4, 1921, Boys Club. Subject: "Making the Desert Bloom." Speaker: Mr. C. J. Blanchard, Chief Statistician, U. S. Reclamation Service, Washington, D. C. Attendance 250.

Providence.—January 17, 1921. Providence Engineering Society Rooms. Joint meeting of the Providence Engineering Society and the Providence Section of the A. I. E. E. Subject: "Survey of the Proposed Superpower Zone." Speaker: Mr. William S. Murray. Attendance 400.

February 9, 1921, Providence Engineering Society Rooms. Subject: "Switching Equipment for the New England Power System." Speaker: Mr. E. W. Dillard, Assistant Electrical Engineer of the Power Construction Company of Worcester, Mass. Attendance 30.

Rochester.—January 28, 1921. Subject: "Electric Ship Propulsion." Lieutenant R. D. DeWolf, of the New York State Naval Militia, Electrical Officer of the U. S. S. *Nevada* during the war. The talk was accompanied by numerous lantern slides showing the development of turbine drive and electric drive in marine propulsion. The economics resulting from the use of electric drive were clearly pointed out. A moving picture entitled "The Queen of the Waves" showing the development of boat propulsion in America from the primitive methods of the Indian to the completion of the U. S. S. *Mexico*, closed the address. Attendance 72.

St. Louis.—January 26, 1921. Engineers Club. Subject: "The Practical Application of Telephone Repeaters." Speaker: Mr. H. P. Charlesworth, Plant Engineer of the A. T. & T. Co. Attendance 139.

Schenectady.—January 21, 1921, Edison Club Hall. Subject: "Technical Drawings as Applied to Visual Education." Speaker Mr. J. Milnor Dorey, of the Bray Pictures Corporation, New York City. The speaker outlined the application of the use of moving pictures made from drawings in the education for the trades as well as the general distribution of knowledge. Attendance 240.

February 4, 1921. Edison Club Hall. Subject: "Control of Heavy Traction Electric Locomotives." Speaker: Mr. Ray Stearns of the Railway Equipment Engineering Department, General Electric Company, The speaker described the many different systems which have been used for electric locomotives. He began with the 600-volt direct-current system, continuing through the different alternating-current systems and finally to a description of high-voltage direct-current. The different

systems were shown by lantern slides, a locomotive and a wiring arrangement being given in each case. This was followed by general description and illustrations of the methods of regenerative control on the Chicago, Milwaukee & St. Paul Locomotives. At the conclusion of Mr. Stearn's lecture, Mr. W. S. H. Hamilton presented a very interesting talk on practical operating problems where long and heavy freight trains are drawn by electric locomotives. He also described the operating results of regenerative braking and retardation. Attendance 180.

Syracuse.— January 14, 1921, Technology Club. Subject: "The Edison Storage Battery." Speaker: Mr. Walter H. Bancroft, Sales Engineer, of the Edison Storage Battery Co. Attendance 57.

Toronto.— January 28, 1921, Chemistry and Mining Building. Toronto University. Subject: "Technical Education in Canada." Speaker: Mr. Lester W. Gill. Attendance 44.

February 4, 1921, Chemistry and Mining Building, Toronto University. Subject: "The Use of Aluminum Conductors for Transmission Lines." Speaker Mr. Theodore Varney. Mr. Varney opened his talk with a brief summary of the conditions attending the collection of energy for moving trains, suggesting that a satisfactory solution of this problem would be obtained by reducing the clearance to a minimum and supplying a rigid overhead conductor of some light aluminum section. The use of aluminum for power transmission dealt with such points as electrolysis, insulation, tower spacing, sag, wind stresses, splices and methods of installation. A number of slides were shown to illustrate these points and some very interesting pieces of construction, including some very long spans of aluminum were brought to the attention of the audience. Attendance 78.

Urbana.—January 14, 1921, E. E. Laboratory, Univ. of Ill. Subject: "The Manufacture of Watt-Hour Meters." Speaker: Mr. C. R. Horrell, of the Sangamo Electric Company, Springfield, Ill. Attendance 45.

Utah.— January 27, 1921, Commercial Club. Joint meeting of Utah Section A. I. E. E. and Utah Society of Engineers. Subject: "Engineering Opportunities in America's Worldwide Activities." Speaker: Mr. Edwin S. Carman of Cleveland. Attendance 250.

Vancouver.— January 7, 1921. Subject: "The Use of Sem-Diesel Oil Engines in Small Power Plants." Speaker: Mr. Frank Sawford. The paper was well illustrated with lantern slides. Attendance 34.

Washington.—January 11, 1921, Cosmos Club Hall. Subject: "Some Things Engineers Should Know Concerning the Rudiments of Corporate Finance." Speaker: Mr. Ralph D. Mershon. Attendance 152.

February 8, 1921, Cosmos Club Hall. Subject: "Superpower and its Relation to Capital." Speaker: Mr. Harold Goodwin, Jr. The talk was illustrated by lantern slides. Attendance 160.

Worcester.— February 2, 1921. Worcester Polytechnic Institute. Subject: "Superpower and Its Relation to Industry." Speaker: Mr. Henry Flood, Jr. Attendance 135.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—January 20. 1921. Papers were presented by Messrs. C. E. Reid and J. M. Dickenson on "Late Developments in the Electrical World." Attendance 26.

University of Arkansas.—January 11, 1921. Election of officers as follows: Chairman, Fred Moore; Vice-Chairman. R. Joerdon; Secretary, S. M. Sharp; Treasurer, G. R. Kilborn; followed by an illustrated lecture on a four wheel drive motor truck. Attendance 18.

January 25, 1921. Subjects: "Development of Radio Service in America" by S. M. Sharp; "Tendencies in the Design of the Power Stations" by W. M. Brewer; "Borrow and Develop Policy—Better than one of Deflation" by Max Ware; "Developments in Material Handling Methods" by Rex Kilborn. Attendance 11.

February 1, 1921. Subjects: "Tendencies in the Design of Power Plants" by W. M. Brewer; "Chances for Technical Graduates with the Westinghouse Company" by W. L. Teague. Attendance 13.

Armour Institute of Technology.—December 10, 1920. Subjects: "The Chicago Lake-Front Improvement" by J. J. O'Rourke; "Machine Switching Telephone System" by G. H. Kelley; "The Development of the Synchronous Converter" by T. L. Albee. Attendance 22.

December 15, 1920. Subjects: "The Ardois System of Signalling" by F. V. Walters; "Gas Engines as Prime Movers" by R. J. Grant; "The Present Outlook for the Engineering Graduate" by Leslie Weiss. Attendance 22.

January 6, 1921. Subject: "Radio Communication Within An Infantry Division" by H. R. Wing. Attendance 28.

Bucknell University.—January 21, 1921. Subject: "The Advantages of Electrical Engineering." Speaker: Prof. R. H. Rhodes. This was followed by an illustrated lecture on the F. W. D. Motor Truck. Attendance 24.

California Institute of Technology.—January 13, 1921. Mr. H. S. Steele, President of the United States Electrical Manufacturing Co. of Los Angeles, gave an illustrated talk on transformer design and construction. Attendance 31.

Case School of Applied Science.—January 11, 1921. Mr. A. F. Wilson of the Ohio Bell Telephone Company, gave an illustrated talk on the changing of the Cleveland Telephone System from the manual to the automatic. Attendance 53.

February 8, 1921. Subject: "Human Repair Work." Speaker: Mr. Ray Finger. Attendance 26.

University of Cincinnati.—January 11, 1921. Mr. E. B. Smith, of the General Electric Company, gave an illustrated talk on "Control of D-C. Motors." Attendance 65.

January 18, 1921. Mr. E. B. Smith gave an illustrated talk on "A-C. Motor Control." Attendance 78.

January 25, 1921. Mr. E. B. Smith repeated his talk on "D-C. Control." Attendance 53.

Clemson Agricultural College.—January 20, 1921. Subjects: "History of the Gas Engine" by L. G. Smoak; "Internal Combustion Marine Engines" by L. H. Hiers; "Automobile Engines" by H. J. Jones; "Current Events" by C. A. Stevenson. Attendance 31.

February 1, 1921. Subjects: "Prime Movers" by C. Yongue; "Motors and Generators" by B. C. Cobb; "General Applications" by B. O'Neil. Attendance 34.

Drexel Institute.—January 28, 1921. Subject: "Advantages of Starting Engineering in the Drafting Room." Speaker: Charles E. Bonine. Attendance 26.

University of Iowa.—January 17, 1921. Subjects: "Insulators" by G. Miller; "Farm Lighting" by C. Longerbeam. Attendance 31.

January 24, 1921. Subjects: "The Automatic Substation" by R. D. Mott; "The Keokuk Power Plant" by R. C. Mathews; "Practical Test and Remedies for Electrical Wiring Troubles" by R. V. Morse. Attendance 33.

Iowa State College.—January 25, 1921. Subject: "Novel Applications of Electricity." Speaker: Mr. A. F. Riggs, General Electric Company, Chicago, Ill. Attendance 106.

February 3, 1921. The following moving pictures were shown: "The Benefactor" and "Cuban Sugar." Attendance 91.

University of Kansas.—January 12, 1921. Subjects: "Village Street Lighting" by Seymore Cronk '21; "Tendencies of White Way Lighting" by Dana McCall '21. Attendance 28.

Lehigh University.—January 20, 1921. Paper: "Industrial Engineering." Author: Mr. H. P. Liversidge, Philadelphia Electric Co. Attendance 70.

Michigan Agricultural College.—January 26, 1921. Subjects: "Electrochemistry in General" by Mr. W. S. Bersey; "Nodon Valve and Mercury Arc as Rectifying Apparatus"

by Mr. R. S. Backus; "Electricity and Titration" by Mr. Hemans; "Rectification of High-Voltage Alternating Current, and the Precipitation of Solid Particles Out of Gases by Electricity" by Mr. A. R. Carlson. Attendance 32.

School of Engineering of Milwaukee.—A trip to the Allis Chalmers Mfg. Co. Plant was made by the Branch on January 17 and 18. On January 21 a meeting was held at which Mr. A. J. Ackerman gave a short talk on the "Layout of the Plant." Special reports were presented as follows: Products of A. C. Co., by E. T. Webb; Foundry and Pattern Work, by F. J. Renner; Machine Shop, by G. D. Rick; Turbines, by R. W. Groot; Coil Winding, by F. J. Renner; Test Room, by W. A. Smith; Power Plant, by F. J Renner; Illumination of Plant, by L. F. Greve; Accommodations and Labor Conditions, by I. L. Illing; ystems of Engineering Department, by A. J. Ackerman. Attendance 60.

University of Minnesota.—January 7, 1921. Subject: "Features of the New C. M. & St. Paul Electric Locomotive." Speaker: Mr. Q. W. Herschey, Westinghouse Elec. & Mfg. Co. Attendance 103.

University of Missouri.—December 8, 1920. Subject: "Railway Electrification." Speaker: Mr. C. Bethel, Westinghouse Elec. & Mfg. Co. Attendance 54.

January 24, 1921. Subject: "Third Brush Control of Automotive Generators." Speaker: Mr. M. E. Epstein. Attendance 25.

February 7, 1921. Subject: "Opportunities for the Young Engineer in the Telephone Field." Speaker: Mr. R. H. Baxter. Attendance 25.

Montana State College.—December 17, 1920. Paper: "Street Lighting Practise." Speaker: Mr. K. A. Hills, General Electric Co., Butte. Attendance 51.

University of Nebraska.—January 20, 1921. This meeting was given over to a general discussion of summer employment for engineering students. Mr. F. W. Norris and Mr. Fred Acton described the General Electric test course and gave their experiences in Schenectady and Pittsfield. Mr. H. O. Peterson described his summer's work with the Westinghouse Elec. & Mfg. Co. Mr. C. O. Hedges discussed his summer's work with the Minnesota and Ontario Paper Co. Attendance 21.

University of North Carolina.—January 7, 1921. Subject: "The Illuminating Engineer; His Work and How He Does it." Speaker: Mr. James M. Ketch, National Works of General Electric Company. Attendance 45.

January 28, 1921. Subjects: "Thawing With Electricity" by Mr. T. E. Hinson; "Vacuum Tubes" by W. F. Allston; "Wireless Telephony" by T. B. Smiley; "The Edison Industries" by O. W. Freeman. Attendance 30.

University of Notre Dame.—January 17, 1921. Subjects: "Life of John Clerc-Maxwell" by R. A. Black and "Life of Michael Faraday" by W. L. Shilts. Attendance 18.

February 7, 1921. Subjects: "Surveys of the Indiana-Michigan Electric Company" by A. Butine and "Life of Joseph Henry" by J. Huether. Attendance 16.

Ohio Northern University.—January 19, 1921. Subjects: "Submarine Propulsion" by C. E. Walker; "Gyro Compass" by Frank Veverka. Attendance 28.

February 2, 1921. Smoker and talks by faculty. Attendance 50.

Oregon State Agricultural College.—January 12, 1921. Four reels of motion pictures were shown at Y-Hut. Lent by Ford Motor Co. and General Electric Co. Attendance 31.

February 10, 1921. Subject: "Commercial Side of Engineering." Speaker: Mr. A. C. McMicken, of the Portland Railway, Light and Power Company. Attendance 200.

University of Pittsburgh.—January 18, 1921. Election of officers as follows: Chairman, C. W. Merritt; Vice-Chairman, S. L. Pendleton; Secretary, C. B. Nennett. Professor H. E. Dyche gave a short talk on the scope and purpose of the A. I. E. E., with particular reference to the Student Branches. Attendance 25.

January 25, 1921. Talks as follows: "Lubrication, With Particular Reference to Railway Motors" by C. W. Merritt; "An Electrical Device Used During the War for the Detection of Enemy Batteries" by C. A. Anderson; "Safety Measures, and Their Application to the Electrical Industry" by W. H. McCardy. Attendance 24.

February 1, 1921. Talks as follows: "Natural Draft in Boiler Rooms" by R. A. Young; "The Bottle Industry" by Frank Braum; "The Production End of Manufacturing" by Lee S. Pendleton. Attendance 28.

February 15, 1921. Talks as follows: "The Electric Furnace" by E. H. Banks; "The Building and Operation of Oil Fields in Northwestern Pennsylvania" by R. J. Helfrich; "The Engineer in Public Life" by W. J. Zuck. Attendance 24.

Purdue University.—January 11, 1921. Film entitled "The Queen of the Waves" was shown. Attendance 43.

January 22, 1921. Joint meeting with the Indianapolis-Lafayette Section A. I. E. E. Subject: "Professional Men and the American Institute of Electrical Engineers." Speaker: Mr. A. W. Berresford, President A. I. E. E. Attendance 104.

February 1, 1921. Subject: "Explanation and Demonstration of High-Voltage Phenomena." Speaker: Mr. K. B. McEachron. Attendance 406.

Syracuse University.—February 4, 1921. Subject: "Automatic Substations." Speaker: Mr. L. Lyman. Attendance 13.

February 11, 1921. Subject: "Arc Welding." Speaker Mr. Chapin. Attendance 13.

University of Virginia.—January 20, 1921. Subjects: "Colorimetry of Nearly White Surfaces" by Mr. Gilchrist; "Superpower Survey" by Professor Rodman. Attendance 15.

February 10, 1921. The following motion pictures were shown "Big Deeds"; "The King of the Rails"; "Cuba, the Island of Sugar." Attendance 15.

Virginia Polytechnic Institute.—January 24, 1921. Mr. Painter gave a very interesting and instructive talk, based upon practical experience, on "Automatic Starters for D-C. Motors." Mr. Bailey gave a talk, with a practical demonstration, on "The Mercury Vapor Rectifier." Attendance 43.

February 2, 1921. Messrs. Bailey and Grear gave a very interesting lecture, accompanied by slides, on "The Part Electricity Played in the Building and the Operation of the Panama Canal." Attendance 36.

University of Washington.—January 11, 1921. Paper. "The Skagit River Transmission Line." Author: Mr. W. T. Batchellor, Secretary of the Seattle Section A. I. E. E. Attendance 18.

State College of Washington.—January 21, 1921. Election of officers as follows: Chairman, Charles Carpenter; Vice-Chairman, Albert Carlson; Treasurer, Harry Garver; Secretary, Julian Swanson. A moving picture was shown on how the Northeast Static Generator worked. Attendance 38.

West Virginia University.—January 24, 1921. Subjects: "Manufacture of Insulators" by J. L. Hark; "The Oscillograph" by C. M. Hill; "Life of Michael Faraday" by C. A. LaPoe; "Maintenance of Interior Lighting Systems" by H. S. Shinn. Attendance 13.

University of Wisconsin.—January 26, 1921. Business meeting and election of officers as follows: Chairman, R. E Hantzsch; Secretary-Treasurer, R. H. Herrick. Attendance 22.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

SERVICES AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL *are not acknowledged by personal letter, but unless the applicant is otherwise advised his notice will appear in the coming issue.*

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, 33 West 39th Street, New York City, the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Correspondence relating to replies to advertisements returned to the Bureau will be held in the Bureau for one month only.

Positions of the Bureau are on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

INSTRUCTORS: All engineers willing to consider teaching positions are invited to register with Employment Service The Bureau has been called upon to fill more positions, varying in grade f rom laboratory assistant to heads of departments in various engineering and technicals school of this country, than it has been able to do from among the men now registered. Blanks for purpose of registration and information regarding the Bureau may be had by addressing W. V. Brown, Manager, 29 West 39th Street, N. Y. City

FIRST CLASS MECHANICS for electrical measuring instruments. Men with executive ability only will be considered. Location Mass. Interview from 9-5 p. m. January 5th, at 29 W. 39th St., N. Y. City. Z-2657.

COMBUSTION ENGINEER. Technical graduate. Two or more years experience, to take charge of tests and investigations of combustion and operating problems. Applicant to state education, training, experience and salary desired. Location Eastern Ohio. Z-2658.

YOUNG MAN WITH TECHNICAL EDUCATION and experience in the design, construction and operation of 2200 volt or standard city distribution lines. Reply giving education experience, references and salary expected. Z-2644.

SALES ENGINEER. Must be a technical graduate with E. E. degree between 22-35 years old. Some sales, testing and repairing experience in small motors desirable. Location New York City. Z-2648.

MECHANICAL ENGINEER for a veneer package plant, steam power plant operation; electrical plant operation and maintenance; woodworking machine maintenance; planer-saws, veneer lathe and clipper, stapling machines, tenoner nailers. Location Ga. X-4.

SALES MANAGER & SALES ENGINEER. Electric heating appliance (especially for domestic cooking) experience desirable. Must have sales manager experience. Application by letter only. Location Wisconsin. X-12.

SALES EXPERT AND SALES PROMOTION MAN with thorough experience in direct and magazine advertising, knowledge printing and electrotype requirement. Able to write "Peppy" copy. Bring sample of work. Electrical experience desirable. Age 26 to 29, not over. X-23.

ELECTRICAL STATION LAYOUT, DESIGNING DRAFTSMEN, experienced men. Preference given technical graduates Location Canada. X-24.

INSTRUCTOR OR ASSISTANT PROFESSOR IN PHYSICS. Must be a graduate engineer not over thirty years old with some teaching experience. Application by letter only. Term will begin January 31, 1921. Location New York City. X-38.

TECHNICAL GRADUATE for Instrument Laboratory. Must have had actual manufacturing experience on electrical measuring instruments. Location New Jersey. X-58.

ASSISTANT PHYSICIST for research work with government. Location New Jersey. X-60.

ELECTRICAL ENGINEER for general instruction work in a correspondence school. Some practical engineering experience required. Application by letter only; give complete information. Location New York City. X-63.

HIGH-GRADE Sales Engineer. Must be live wire—one acquainted with power equipment. Position will pay salary and commission of from eight to ten thousand dollars a year. Prefer man between ages of thirty and forty. No one will be considered whose past sales record does not prove him worth this amount. Position now open. All replies confidential. Location Illinois. X-68.

POWER PLANT SWITCHBOARD OPERATORS with hydroelectric experience. Two years contract. Location Peru. X-84.

ELECTRICAL ENGINEER to install telephones and switchboard. Two years contract. Location Peru. X-85.

CHIEF OPERATING ENGINEER, for two power houses. One plant consisting of five 350-h.p. B. & W. boilers with superheaters and stokers, one 1250-kw. Westinghouse, turbine, one 300-kw. bleeder type Westinghouse turbine, direct current, two compound Corliss type reciprocating pumps for 1200-lb. pressure and one 1250-h. p. compound reciprocating engine in our rolling mill. The other plant has eight 50-h. p. H. R. T. boilers, one Westinghouse high pressure turbine, one De Laval atmospheric pressure turbine, one Curtis mixed pressure turbine, running condensing, a 500-kw. motor-generator set, and two single-cylinder Corliss engines direct-connected to the rolls. Location Connecticut. X-102.

INSTRUCTOR of electricity for Trade School. Should have had several years practical training in the trade; should be well informed regarding the fundamentals of electricity, and must meet the ordinary character requirements. Teaching experience is essential. Will be expected to handle classes in elementary principles of direct and alternating currents and the application, operation, and repair of d-c. and a-c. apparatus. Classes consist of boys fourteen years of age and over, and ex-soldiers sent here under the Rehabilitation Act. The school is in session twelve months in the year. Work to begin on or before February 10th. Location Missouri. X-116.

RECENT ELECTRICAL GRADUATE of a Leading Engineer College wanted for power equipment, development and research in New York City. Two or three years experience in electrical power plants and machines desirable. Work of a consulting nature including supervision of design and the development of control systems and operating methods for machines, switchboards, gas engines and batteries; cost studies, etc. Broad theoretical foundation and acceptable personality are essential. Salary $1800 to $2400 to start, depending on experience. Good opportunity for advancement. Give complete details. Technical and personal. X-143.

EXCELLENT opportunity offered in Shanghai, China for thoroughly experienced designing erecting power plant engineer to handle well-known equipment for well-known established export organization able to finance any installation. Willing to give responsible capable engineer good salary and opportunity to secure up to twenty thousand dollar interest partnership in firm. Only high grade financially able man considered. Give detailed experience references first letter. All confidential. X-142.

MANAGER to take charge of mechanical part of plant manufacturing a line of automobile parts used by manufacturers of cars and trucks, also some machine tool parts, made on Automatic and Hand Screw Machines, Punch Presses, Millers, Drillers, Tappers, Threaders and Polishing Equipment. These parts, are made in quantity lots on above machines. Location Ohio. X-171.

SUPERINTENDENT to have complete charge of a plant manufacturing plants and varnishes. Location Dela. X-181.

SALES EXECUTIVE. Should be familiar with construction and mining machinery of all kinds and should be able to lay out and plan a sales campaign in the West Virginia territory for this class of equipment. Should also have some knowledge of machine tools and electrical equipment but his knowledge need not be too accurate as they already have a high priced electrical engineer. Good salary to right man and in addition a share in the success of the business in addition to salary. Location West Va. X-182.

ARCHITECTS INSPECTOR to brake in on roof work. Estimating. One who knows roof constructions. (specific work)—Estimating of roof coverings. Location New York. X-183.

ELECTRICAL ENGINEER, familiar with maintenance work in publishing plant. Must understand repairs, extension to plant, etc. Must be between 32-38 years old. Application by letter only. X-185.

PROGRESSIVE firm in Middle West needs man to sell high grade electrical device in large units to city gas, coke oven and steel industries. Applicant must be graduate of technical university of good standing. Experience in engineering sales work or in operating in any of above industries will be advantage, but most importance will be attached to well balanced engineering sales ability, desire for hard work and a personality adapted to the exploitation of a proven device. In reply state education training and experience to date and when available. X-190.

ENGINEER for editorial work in electrical periodical. Will be required to look after personal items and also description of electrical apparatus, plants, etc. Application by letter only. X-188.

MEN AVAILABLE

ELECTRICAL ENGINEER, University of Illinois graduate '12, Central station experience on substation design, transmission line specifications and rights, power rates and contracts. Industrial plant experience on power, heat and light installations and superintendence of operation. Desires position of stability and with chances for advancement. E-2517.

PROFESSORSHIP OF ELECTRICAL ENGINEER. Have taught in large university for fifteen years, electromagnetic theory, d-c. and a-c. practise, transient phenomena, radio telegraphy, etc. In charge of important engineering operations during the war (Major). Now on engineering research. Desire suitable position in university with increasing research activities. E-2518.

ELECTRICAL ENGINEER, age 25; married. Two years public utility and one and one half years manufacturing experience, desires sales engineering connection. Location preferred central states. E-2519.

ENGINEER, age 42, large company, salary $7000.00. Wants to join smaller organization. Fourteen years one concern. Twenty years development manufacture sale electrical devices particularly telephones, ignition equipment. Successful inventor having brilliant record developing patent situations and perfecting inventions. Salary secondary, primary requisite congenial connection with real future. E-2520.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate. Seventeen years general experience in electrical and mechanical engineering, and in charge of construction work in connection with all kinds of power developments, transmission distribution, electric railways and industrial plants, available for new position immediately. E-2521.

DESIGNING ENGINEER, with exceptionally broad experience and highest references on distribution and substation work desires to join a progressive engineering firm and will make a reasonable investment to secure an interest in the business. E-2522.

PLANT SUPERINTENDENT OR FOREMAN. Age 24; married. Experience in large generating plants and substations of nearly every description. At present employed as operator. Would consider operating position with chances for advancement. Location anywhere; South America preferred. Can give best of references. Associate A. I. E. E. E-2523.

GENERAL LINE FOREMAN ten years experience on maintenance and construction installation. Also able to handle chief electrician of mines both a-c. and d-c. Technical training. Can handle large force of men. Married; age 38; available at once. E-2524.

TECHNICAL GRADUATE desires position in radio or electrical laboratory on research and experimental work; radio work preferred. Four years experimental work in laboratory. Now employed as assistant instrument inspector by large public utility company. E-2525.

ELECTRICAL AND MECHANICAL DRAFTSMAN age 33; married. Two years experience on practical and electrical work. Ten years experience in machine design and electrical dreafting. Eight years with present employer. Desires position with chance of advancement. Salary $2500. Location Cleveland. E-2526.

TECHNICAL GRADUATE. Three years in mill, power plant, and electric railway maintenance. Three years teaching both General Science and as head of electrical wiring department of eastern technical school; desires position as works engineer or chief electrician. Prefer eastern states. E-2527.

TECHNICAL GRADUATE, age 35; single, desires position with large company as electrical engineer where a thorough knowledge of electrical construction and motor application and ability to handle men would be appreciated. Salary $3600. Slight knowledge of Spanish. Go anywhere. Employed. Thirty days notice required. E-2528.

MECHANICAL SUPERINTENDENT, chief engineer and master mechanic of textile mills, age 39, married; technical graduate, practical mechanic, thorough knowledge of steam plant economy, electric drives, machinery installations for industrial plants and building construction. First class Massachusetts engineers license. E-2529.

TECHNICAL GRADUATE in electrical engineering desires employment for evenings and spare time, amounting to fifteen hours per week. Will accept any engineering problem or investigation. Have had experience in efficiency investigations of steam plants, electric motor design, radio and telephone engineering. Location St. Louis, Mo. E-2530.

ELECTRICAL ENGINEER GRADUATE, 12 years experience at industrial engineer with large companies. Work includes design of power and industrial plants, supervision and control of plant operations and application of modern engineering methods to standardizing and cheapening production. A. I. E. E. member. E-2531.

TECHNICAL GRADUATE. Is there an opportunity in some electrical engineering department for young man, age 23, protestant, high school graduate business education, I. C. S. graduate in complete electrical engineering, with two months experience as electrician helper, also two years experience as power station and switchboard operator? Associate of A. I. E. E. E-2532.

ELECTRICAL ENGINEER. For sale. Eleven years installation and repair, motors generators, power house, substation, illumination. Capable and efficient man. Sales training. At present electrical superintendent of power and light. Write for details before closing the position you have open. Location no object. Permanent mutual satisfaction only requirement. Best possible references. E-2533.

YOUNG MAN, age 26; single, desires position as electrician or storage battery man with good firm. Four years electrical and six years storage battery experience. Speaks Spanish and has no objection to going outside United States. Can furnish best of references. E-2534.

GRADUATE ELECTRICAL ENGINEER. Ten years practical experience; seven years with large iron mining company. Experienced in design, and operation of steam and water power plants, transmission systems and industrial applications. Now available for position where advancement depends on results obtained. Prefer part outside work. Age 31; married. Best reference. E-2535.

GENERAL ENGINEERING WORK, wanted by member, now employed as investigating engineer by high grade investment securities house in New York. Desires change that will give him active (partial or entire) outside or road work in which he may utilize twelve years experience in sub and central station design, installation and operation, with the country's largest central station company, and four years on hydro and sub-station design and hydraulic investigations and tests with well known engineering company. E-2536.

ENGINEER, technical graduate, experienced in sales, construction, inspection, and advisory work in connection with power stations, electric railways, and large industrial plants, will consider position in advisory capacity with financial investment house or importing or exporting concern. Interview by appointment. E-2537.

ENGINEER, nine years and eight months in last position as chief engineer and superintendent of works in Gas and Electric plant 6000-kw. electric plant and 600,000-cubic-foot gas plant. Open for immediate position in East preferred. Holds 1st class Mass. license. Associate A. I. E. E. Salary $3500. Age 48. E-2538.

OPPORTUNITY wanted with contractors, engineers or public utility. Five years 66 kv. transmission; three years pole lines; eight years industrial installations, illuminations (textile) Technical training, Assoc. A. I. E. E. Fellow Aerial League America. Present employed supervising estimating and. engineering large textile plant. Age 34; Canadian. Prefer any section Canada. Good reasons for changing. References. Present location Mass. E-2539.

ELECTRICAL ENGINEER, age 39, graduate M. I. T. Fifteen years practical experience with all kinds of electrical construction, operation, and maintenance. Deisres position as supervising engineer on construction or electrical engineer for industrial concern. Best references. Salary $2800. E-2540.

ELECTRICAL ENGINEER, 12 years experience including responsible charge of electrical operation and maintenance of large modern power station and sub-stations, electrical design and also construction of power and sub-stations. Application of motors to industrial service including cranes and other material handling devices. E-2541.

ELECTRICAL ENGINEER, age 27. Five years experience in power plant distribution, electric railway and industrial construction, including purchasing, valuation, estimating, draughting and field work, resigning as electrical engineer. Three years experience in metal parts manufacturing including inspection design and development, production and factory systems and accounting, resigning as manufacturing manager. Now with consulting engineering firm but seeks positions in construction or operating fields. Future opportunity primary, salary secondary. New York City or vicinity. E-2542.

ELECTRICAL AND MECHANICAL ENGINEER, age 26, at present employed, desires position with industrial concern or in hydroelectric work. Several years experience in power plant operation, industrial plant layout work and in estimating costs of construction. Available on two weeks notice. Salary expected $250 per month. E-2543.

GRADUATE ELECTRICAL ENGINEER. Six years experience with General Electric Company, including work covered by testing department and switchboard department; also two years additional experience as sales engineer with other companies. Wishes employment with reliable manufacturer on general engineering or research work. E-2544.

TECHNICAL GRADUATE, age 26; married. Four years testing and development engineering with large manufacturer including; 1½ years research work with government. Desires position with growing concern in middle west in research or industrial engineering. Present salary $3000.00. Available immediately. E-2545.

ELECTRICAL DESIGNING DRAFTSMAN wishes position with large manufacturer on special work. Eight years experience in shop mechanical drafting and detailing with railroad and manufacturing plant; three years wiring and general contracting; three years in service and with consulting engineer, telephone, wireless and power house details. Correspondence course in electrical engineering E-2546.

SALES REPRESENTATIVE would like one or two kindred electrical lines for Chicago district. Graduate Wisconsin 1912. Manufacturing, power and commercial experience; past five years as buyer for large mercantile corporation. Sold over $400,000.00 worth of appliances in 1920. Age 33; married. Available at once. E-2547.

ELECTRICAL GRADUATE, age 29, with four years electrical experience in construction, testing, drafting and design, as well as office work, seeks assistantship to engineer in charge of large power system or with consulting engineer engaged along similar lines. E-2548.

TECHNICAL GRADUATE, age 33; married. Eight years operating and supervising large and small coal-carburated water gas properties, manager gas utility, community 7000, one year tool designing automobile plant and one year purchasing and costs auto trailer industry. Desires position with future. Available short notice. E-2549.

GRADUATE ELECTRICAL ENGINEER, two years G. E. test and calculating room. Seventeen years design, construction and operation of power plants, substations, overhead and underground feeder lines on railway electrification. One year superintendent of building construction. Desires permanent sales or executive position with industrial or operating company. E-2550.

ELECTRICAL ENGINEER-PHYSICIST. Engineer in charge of installation of first commercial wireless telephone system in Canada for large hydroelectric company, also in charge of work on protection and on mitigation of inductive interference of telephone lines. Extensive experience in research work, as well as electric power station operation and maintenance. Available on short notice. Desires position with power company or with manufacturer or electrical 'equipment. Location preferred Canada E-2551.

GRADUATE ELECTRICAL ENGINEER, age 30; married. Five years experience including G. E. test, central station test department instructor in radio division of air service and manager of small hydroelectric company. Desires position with hydroelectric company, central station company or firm of consulting engineers. Available on short notice. E-2552.

ENGINEER, eighteen years successful experience in design, manufacture and sales of alternating and direct current motors. Qualified to assume entire charge of business as factory manager, sales or district sales manager. Age 40; American; available March 1st. E-2553.

ENGINEER AND EXECUTIVE. Five years practical experience doing graduate work at present, desires employment during afternoons as assistant to executive. Has specialized on industrial problems of an economic nature. E-2554.

ELECTRICAL ENGINEER, age 32; single. Nine months testing experience with Westinghouse Electric & Mfg. Company. Four years with large electric railway company. Experience includes electrolysis investigation, cable inspection, and solution of problems pertaining to electric traction and power plant operation. E-2555.

ELECTRICAL ENGINEER, thirteen years experience in manufacture, testing and designing of alternating current motors and generators. At present in charge of electrical and mechanical design of alternating and direct-current motors and generators. Desires to connect with one of smaller progressive companies. Available in sixty days. E-2556.

ELECTRICAL ENGINEER, desires responsible position with central station. Ten years experience on large systems, systems power stations, substations, transmission, and a-c, and d-c. distribution. Cansup ervise the making of plants and handle construction and operation. Associate A. I. E. E. and technical graduate. Best references from former employers. E-2557.

EXPORT ENGINEER. Graduate electrical and mechanical engineer desires connection with firm, that needs man acquainted, through ten years experiences with electrical manufacturers material, and also acquainted with languages and social conditions of Scandinavian countries. At present in charge of electrical department, with large contracting and designing engineering company. E-2558.

YOUNG MAN, technically trained in electrical engineering. Four years practical experience in repair works. Thorough knowledge of Spanish. Has travelled in Latin American countries. Ambitious and willing worker. Age 22; single. Will accept position as assistant to electrical engineer, interpreter or translator. Location no object. E-2559.

GENERAL OR WORKS MANAGER. Mechanical and electrical engineer. 15 years executive industrial experience in management, sales, finance, factory organization and quantity production. Can handle old established or develop new manufacturing propositions from raw materials to the marketing of finished product. E-2560.

ELECTRICAL ENGINEER. Yale A. B. Massachusetts Institute of Technology, S. B. in electrical engineering. Harvard S. B. E. E. Nine years experience in designing and construction of steam railway electrification, power stations, substations and high tension transmission lines. E-2561.

GENERAL MANAGER of utilities, at present operating twelve electric, eight ice, two water works properties, desires change because individual properties are being sold. Age 37; married, technically trained, exceptionally competent in manufacture and sale of ice. Salary $7500. E-2562.

YOUNG MECHANICAL and electrical engineer with 1½ years experience in industrial and power plant work desires to make connection with industrial, power plant, construction or general consulting concern. Training largely executive in nature. E-2563.

EXPERIENCED ELECTRICAL ENGINEERING INSTRUCTOR a-c. and d-c. theory and laboratory and electrical transmission, B. S. in E. E. 1917. Three years experience in power plants Signal Corps and assistant to consulting engineer, one year teaching. Desires associate professorship in recognized engineering college beginning Sept. 1921. E-2564.

PUBLIC UTILITY MANAGER, electrical engineer, member A. I. E. E., American. Broad experience construction, operation and management light, power and street railways, steam and hydroelectric. Available at once, this country or Spanish America. Thorough knowledge of Spanish. E-2565.

ELECTRICAL SUPERINTENDENT. Services available on short notice, power house, substation, industrial plants, distribution overhead and underground, construction or maintenance. 22 years experience; age 42; location anywhere. At present employed but looking for permanent location. E-2566.

ENGINEER EXECUTIVE, university graduate, electrical, mechanical, sound business training. Construction, sales and purchasing experience. Until recently in charge of exports New York office well known foreign house of contractors merchants, managers. Good knowledge domestic industry and foreign conditions. Associate A. I. E. E. and A. S. M. E. Age 33; married. Good references. E-2567.

ELECTRICAL ENGINEERING GRADUATE, 1919 B. S. Age 23; wishes to become associated in work of commercial character with concern handling electrical equipment. General Electric test; excellent English and Russian, full of energy and aflame with ambition. Entrance salary dependent on future possibilities. Available on short notice. East preferred. E-2568.

GRADUATE MECHANICAL ELECTRICAL ENGINEER. Experience; two years in radio research; two years in radio design in government service; two years in manufacture of radio apparatus; one year in engineering sales of industrial equipment. One year as plant manager of organization building $500,000 worth of radio and similar equipment per year. Available after March 1st, for production or engineering sales work. E-2569.

YOUNG RAILROAD MAN, desires position as superintendent or master mechanic with small street or interurban railway property. 8 years experience in construction, maintenance and operation, 5 of which were spent with two leading New York rapid transit systems. At present employed as chief electrician of large power company but desires to return to work in which he has previously specialized. References. E-2571.

RESEARCH AND DEVELOPMENT ENGINEER, age 27; married; associate A. I. E. E.; college graduate. Six years of research and development both electrical and mechanical. Capable of handling independent investigations and getting results. Prefer position with manufacturing concern where experience can be applied to production problems. Acquainted with electrical machinery and storage batteries. Minimum salary $2400. E-2572.

GRADUATE ELECTRICAL ENGINEER, age 31. One and one-half years G. E. test; one year G. E. radio research; three years broad electrical experience; radio experience in the army; and two years teaching electrical engineering in western university. Desire teaching position in university or engineering school. E-2573.

GRADUATE ELECTRICAL ENGINEER, 1917, Associate A. I. E. E. age 26; married. Two years experience as manager of steam plant desires position as assistant to electrical engineer or with electrical contractor. Present salary $2200. References furnished on request. E-2574.

ELECTRICAL ENGINEER, nine years experience in design and operation of electric light power systems, desires position with central station company or large engineering firm. Can handle men. Experience includes power stations, substations, transmission, and a-c. and d-c. distribution, overhead and underground. University graduate; married. E-2575.

ENGINEER. Associate A. I. E. E. age 32; married. Fourteen years practical electrical and steam experience construction, testing, operation, and maintenance. Technical education self attained. Desire charge of electrical plant, transmission lines, wiring, etc. Location West. E-2576.

TECHNICAL GRADUATE, American. At present in charge of operation, construction and maintenance of electrical and mechanical equipment of large mine in Spanish America. Available within sixty days. Married. Speaks Spanish fluently. Present salary $4000. Would consider similar position with industrial mining or central station anywhere. E-2577.

ELECTRICAL ENGINEER, thoroughly equipped for organization and direction of research and development of electrical apparatus or materials, having recently completed notable work in connection with automotive, magneto and ignition equipment. E-2578.

ELECTRICAL ENGINEER, 1917 Illinois electrical engineering graduate, age 28. Sound business training; six years of railway, power shop, and distribution experience. Salary $200.00 per month. E-2579.

TECHNICAL GRADUATE, with ten years experience in field, office, and laboratory engineering with power plant equipment and electrical precipitation processes. Sales and patent experience. Desires position as development engineer or in executive capacity. E-2580.

YOUNG ELECTRICAL ENGINEER, age 23; graduate of 1919, desires position in or near New York City. Experience includes G. E. test course (7 months) one-half year of central and substation testing and some teaching. E-2581.

ELECTRICAL ENGINEER, on month's notice. Desires position as sales or service engineer. Seven years experience on actual construction, installation and testing work. Broad knowledge of general testing and meter laboratory work. Degree E. E. Desires territory near Indiana. E-2582.

PRODUCTION MANAGER, assistant works manager. Graduate electrical engineer. Age 26; married. Former Captain Engineer Reserve Corps. Desires position offering an opportunity for advancement. At present production manager of a plant of 50,000 unit capacity. Middle Western location preferred, but not essential. E-2583.

TECHNICAL SCHOOL graduate, age 23; with three years college training towards degree in Electrical Engineering; also experience as assistant superintendent in vocational school electricity and machine shop practise, wishes electrical installation, or work not too confining; preferably outside. Any location considered. Preferably eastern United States. E-2584.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute Records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1. Leo Arany, Room 201, Parkway Bldg., Broad & Cherry Streets, Philadelphia, Pa.
2. De Los De Tar, 411 East 15th Street, Kansas City, Mo.
3. Richard H. Gust, Mountain States Tel. & Tel. Co., Pocatello, Idaho.
4. Alex. E. Keith, 138 Elm Street, Hinsdale, Ill.
5. H. S. Logan, 215 15th Street, Seattle, Wash.
6. Harry I. Shire, 1310 Majestic Bldg., Detroit, Mich.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

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Setze, Henry R., Electrical Tester, Georgia Railway and Power Co.; res., 144 E. Pine St., Atlanta, Ga.
Shand, Fred B., General Engineering Dept., Hydro-Electric Power Commission, 190 University Ave., Toronto, Ont.
Shapiro, Louis, Central Station Electrical Draftsman, T. E. Murray, Inc., 55 Duane St., New York, N. Y.
Shouse, Frederick A., Electrical Installation Supt., Walker Electric and Plumbing Co., Atlanta, Ga.; Danville, Va.
*Siegel, Robert C., Student, University of Wisconsin; res., 110 S. Henry St., Madison, Wis.
Simcock, John H., Master Mechanic, E. B. Badger and Sons Co., 75 Pitt St., Boston, Mass.
*Simons, James A., Electrical Engineer, Engineering Dept., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Smelser, William A., Teacher of Electrical Subjects, Vancouver School Board Offices; res., 2158 13th Ave. West, Vancouver, B. C.
Smith, Nehill F., Electrical Engineer, 33 Fourth St.; res., 2344 15th St., Troy, N. Y.
Spangler, William N., Asst. Supt., Telegraph and Signals, Pennsylvania R. R., Broad Street Station, Philadelphia, Pa.
Spargur, Herbert W., District Plant Supervisor, New York Telephone Co., Huntington, N. Y.
Sparshott, Alfred H., Engineer in Charge of Power Station, Georgetown Power Station, Wisconsin Ave. and K St., Clarendon, Va.
Spencer, T. Harold, American Bosch Magneto Corp.; res., 32 Chase Ave., Springfield, Mass.
Stebbins, Duton L., Repeaterman, Pacific Telephone and Telegraph Co., Telephone Bldg., Spokane, Wash.
Stederoth, Frederick F., Electrical Maintenance Engineer, Pathe Exchange, Inc., 1 Congress St., Jersey City, N. J.
*Stephens, Charles B., Engineer, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont.
*Stone, Howard B., Engineer, Robbins and Myers Co., Springfield, Ohio.
*Strobel, William F., Student, Brooklyn Polytechnic Institute, Brooklyn; res., 204 E. 72nd St., New York, N. Y.

STRONG, ELMER E., Vice President, Schiefer Electric Co., Inc., 614 City Bank Bldg., Syracuse, N. Y.
STUART, JAMES E. B., Junior Assistant Electrical Engineer, Panama Canal, Balboa Heights, Canal Zone.
SWENSON, IVAR A., Construction Engineer, General Electric Co., 84 State St., Boston; res., 157 Westminster Ave., Arlington, Mass.
THICKMAN, BERNARD, Junior Electrical Engineer, Transit Construction Commission, 49 Lafayette St.; res., 1299 Franklin Ave., New York, N. Y.
THOMAS, CHARLES M., Mechanical Supt., Sanford Spinning Co.; res., 651 So. Main St., Fall River, Mass.
THOMSON, DAVID P., Designing Engineer, General Electric Co., W. Lynn; res., 14 Center St., Cambridge, Mass.
THOMSON, HARRY L., Supt. of Lighting, Hartford Electric Light Co., 266 Pearl St., Hartford, Conn.
THOMSON, MALCOLM, Electrical Engineer, General Electric Co., Lynn; res., 90 Humphrey St., Swampscott, Mass.
THRAILKILL, WILLIAM LOUIS, Apprentice Electrician, Puget Sound Navy Yard; res., 1058 6th St., Bremerton, Wash.
TIKHONOVITCH, BENEDICT S., Engineering Dept., The New York Edison Co.; res., 635 W. 115th St., New York, N. Y.
TOWNE, WALTER I., Engineering Dept., New England Tel. and Tel. Co., Boston; res., 26 Irving St., W. Medford, Mass.
TRAVI, JOHN JOSEPH, Proprietor, General Ignition Company, 1416 Stiles St.; res., 1736 North 22nd St., Philadelphia, Pa.
TUCKER, ALLAN W., Equipment Engineer, Western Electric Co., Inc., 463 West St., New York, N. Y.
*TURNER, HARRISON I., Engineering Dept., General Electric Co., Boston; res., 22 Gage St., Methuen, Mass.
UNDERHILL, GEORGE H., Asst. to Elec. Engineer, Central Hudson Gas and Electric Co.; res., 78 S. Hamilton St., Poughkeepsie, N. Y.
VANDERHOOF, ALEXANDER, Testing Dept., American Transformer Co.; res., 533 Hawthorne Ave., Newark, N. J.
*VAUGHAN, JAMES W., Jr., Sales Engineer, General Electric Co., Atlanta, Ga.
VEDDER, WILSON Y., Asst. Supt. of Electrical Construction, Brooklyn Edison Co.; res., 1625 E. 15th St., Brooklyn, N. Y.
VOGEL, FRED J. Transformer Engineering Dept., Westinghouse Elec. and Mfg. Co., E. Pittsburgh; res., 754 Wallace Ave., Wilkinsburg, Pa.
WALKER, ROBERT L., Electrical Repairman, Georgia Railway and Power Co.; res., 40 Stokes Ave., Atlanta, Ga.
WALLACE, GORDON S., Division Toll Wire Chief, New England Tel. and Tel. Co., Boston; res., 281 Faneuil St., Brighton 35, Mass.
*WALLERSTEDT, CARL A., Estimator, The Atlas Portland Cement Co., Northampton; res., 115 N. 5th St., Allentown, Pa.
WALSH, JAMES A., Electrical Engineer, L. K. Comstock and Co., 21 E. 40th St.; res., 2384 Tiebout Ave., New York, N. Y.
*WALTON, ALBERT S., Equipment Man, Long Lines Dept., American Tel. and Tel. Co., Elkton, Md.; res., Newark, Del.
WEBBER, FRANKLIN C., Salesman, U. S. Electrical Mfg. Co.; res., 738 W. 56th St., Los Angeles, Cal.
WHITMORE, WALTER, Supervising Engineer, New England Tel. and Tel. Co., 50 Oliver St., Boston, Mass.
WHITNEY, RUSSELL L., Graduate Student, Westinghouse Elec. and Mfg. Co., Wilkinsburg; res., Moore, Pa.
WHORF, EDWARD W., Traffic Engineer, New England Tel. and Tel. Co., 50 Oliver St., Boston, Mass.
WILBURN, SIDNEY D., Telephone Transmission Engineer, American Tel. and Tel. Co., 823 Boatman's Bank Bldg., St. Louis, Mo.
WILKINSON, READING, Engineer, Birmingham Railway, Light & Power Co., 2100 First Ave. North Birmingham, Ala.
WILSON, LEONARD B., Asst. Superintendent, Northern Ontario Light & Power Co., Cobalt, Ont.
*WILTSE, STANLEY B., Instructor, Dept. of Physics & Elec. Engineering Rensselaer Polytechnic Institute; res., 1216 Jacob St., Troy, N. Y.
WINEGARTNER, CARL E., Electrical Engineering Dept., Cleveland Electric Illumination Co., Illuminating Bldg., Cleveland, Ohio.
WINTER, WILIS L., Sales Engineer, Westinghouse Electric & Mfg. Co.; res., 2027 Hyde St., San Francisco, Cal.
WOHLPAT, JOSEPH P., Electrical Switchboard & Panelboard Designer, Lord Electric Co., 140 W. 40th St.; res., 1469 St. Lawrence Ave., New York, N. Y.
*WOLFERZ, ALFRED H., Asst. Electrical Engineer, Western Electrical Instrument Co., Newark; res., 48 Smith St., Elizabeth, N. J.
*WOLFINGER, WESLEY C., Motor Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1410 Northampton St., Easton, Pa.
WOXMAN, CARL A., Construction Engineer, Warren D. Spengler, 200 Marshall Bldg., Cleveland; res., 11 S. Monmouth St., Dayton, Ohio.
WRIGHT, GEORGE P., Technical Employee, American Tel. & Tel. Co., 500 Stahlman Bldg., Nashville, Tenn.
*YORDON, WESLEY J., Asst. Electrical Engineer, Hunter Fan & Motor Co., Fulton; res., 720 Bear St., Syracuse, N. Y.
*YOST, NORMAN S., Winding & Test Depts., Howell Electric Motors Co.; res., 427 E. Grand Ave., Howell, Mich.
ZWALLY, E. J., Automotive Corporation, 5864 Baum Blvd., Pittsburgh, Pa.
Total 270.
*Former enrolled students.

ASSOCIATES REELECTED FEBRUARY 16, 1921

BEHNKE, R. E., Asst. Electrical Engineer, Dwight P. Robinson & Co., Inc., Grand Centrral Palace; res., 2835 Marion Ave., New York, N. Y.
BLISS, ERNEST F.; East Moriches, Long Island, N. Y.
HAISLIP, RICHARD A., Telephone Engineer, Dept. of Development & Research, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
JONES, JULIAN D., Supt., Telegraph & Signals, Eastern Region, Pennsylvania System, Broad Street Station, Philadelphia, Pa.
LEET, ARTHUR W., Transportation Engineer, Mercury Mfg. Co., 816 Union Trust Bldg., Detroit, Mich.
STEPHENS, HERBERT C., Chief Engineer, The Electric Motor & Repair Co., 60-62 Iron St., Akron, Ohio.

MEMBERS ELECTED FEBRUARY 16, 1921

GRAHAM, WARREN C. S., Consulting Engineer, Calle Rividavia 770, Buenos Aires, Argentina, S. A.; res., 5317 Magazine St., New Orleans, La.
HARRISON, JOHN A., Traffic Engineer, The North Electric Mfg. Co.; The Lime Tel. and Tel. Co., 122 So. Elizabeth St., Lima, Ohio.
JONES, WILLIAM S., Electrical Engineer, Bureau of Yards and Docks, Navy Dept., 2943 Navy Bldg., Washington, D. C.
MALING, SILAS Y., Deputy City Electrical Engineer, Municipal Council of Sydney, Town Hall, Sydney, Aus.
MATTHEWS, CHARLES H., Electrical Engineer, M. A. Hanna and Co., 1300 Leader-News Bldg., Cleveland, Ohio.
PEEBLES, JOHN B., Professor of Engineering, Emory University, Emory University, Ga.
SURPRISE, EDWIN M. Equipment Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.
WATSON, WILLIAM G., Managing Director, W. G. Watson and Co., Ltd., 279 Clarence St., Sydney, Aus.
WINTERS, E. P., Chief Electrician, Woodward Iron Co., Woodward, Alabama.

TRANSFERRED TO GRADE OF FELLOW FEBRUARY 16, 1921

GRAY, GEORGE F., Assistant Manager, Engineering Dept., National Aniline & Chemical Co., New York, N. Y.
HAZELTINE, LOUIS A., Professor of Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.
OSBORNE, HAROLD S., Transmission Engineer, American Telephone & Telegraph Co., New York, N. Y.
WATERS, GRANVILLE A., Assistant Chief Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.
WOODBRIDGE, J. LESTER, Chief Engineer, Electric Storage Battery Co., Philadelphia, Pa.

TRANSFERRED TO GRADE OF MEMBER FEBRUARY 16, 1921

APPLEYARD, ARTHUR E., Manager, Minneapolis Anoka & Cuyuna Range Ry. Co.; President, British Columbia & Alberta Power Co. Ltd.; Minneapolis, Minn.
BARNS, BIRD L., A. C. Engineer, Canadian General Electric Co., Peterborough, Ont.
BERNHARD, FRANK H., Editor, E. M. F. Electrical Year Book, Electrical Trade Publishing Co., Chicago, Ill.
CARPENTER, HENRY C., Chief Engineer, New York Telephone Co., New York, N. Y.
EVANS, PORTER H., Engineering Dept., Western Electric Co., New York, N. Y.
FECHT, ARTHUR J., Associate Electrical Engineer, Bureau of Standards, Washington, D. C.
GROSS, BENJAMIN, Chief Engineer, Hatzel & Buehler, Inc., New York, N. Y.
HANNAFORD, FOSTER, General Manager, Twin City Rapid Transit Co., Minneapolis, Minn.
HERRMANN, RAYMOND R., Instructor in Mathematics and Mechanics, University of Minnesota, Minneapolis, Minn.

LEE, CARL, Electrical Engineer, Peabody Coal Co., Chicago, Ill.
PETTY, EDWIN W., Electrical Engineer, H. M. Byllesby Co., Chicago, Ill.
POMEROY, WILLIAM D., Vice-President and General Manager, Goulds Manufacturing Co., Seneca Falls, N. Y.
POOL, RALPH Y., General Superintendent, Intermountain Railway Light & Power Co., Colorado Springs, Colo.
STICKNEY, H. RUSSELL, Electrical Engineer, Jackson & Moreland, Boston, Mass.
STOKES, STANLEY, General Supt. Outlying Plants, Union Electric Light & Power Co.; Vice-President & General Manager, Commercial Telephone Co., St. Louis, Mo.
WHALEN, JAMES M., Vice-President & Manager of Machine Dept., Northwestern Electric Equipment Co., St. Paul, Minn.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held November 29, 1920, January 3, February 7 and 11, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To grade of Fellow

ACKER, ALBERT J., Electrical Engineer of Shaw Crane Works for Manning, Maxwell & Moore, Inc., Muskegon, Mich.
EWING, DRESSEL D., Professor of Electric Railway Engineering, Purdue University, Lafayette, Ind.
FINLAY, WALTER S., JR., Vice-President, American Water Works & Electric Co., New York, N. Y.
MACLACHLAN, WILLS, Electrical Engineer, Toronto, Ontario.
MOORE, EDWARD T., Electrical Engineer, Halcomb Steel Co., Syracuse, N. Y.

To grade of Member

ABBOTT, LEWIS W., Supervisor of Equipment, New England Tel. & Tel. Co., Boston, Mass.
BARNES, HAROLD B., Chief Engineer, Golden Fleece Mining & Milling Co., Denver, Colo.
BEAUCHAMP, LEON, Vice-President and Chief Engineer, The Solex Co. Ltd., Montreal, Quebec.
BRADLEY, HAROLD H., Commercial Engineer, Latin American Sales Dept., International General Electric Co., Schenectady, N. Y.
BROWN, GEORGE N., District Manager, Pittsburgh Transformer Co., New York, N. Y.
COOPER, CHARLES P., General Manager, Ohio Bell Telephone Co., Cleveland, Ohio.
DEFOREST, CORNELIUS W., Manager, Electrical Dept., Union Gas & Electric Co., Cincinnati, O.
FORGES, FREDERICK A., Consulting Engineer, New York, N. Y.
HOOD, JOHN, Local Engineer, General Electric Co., San Francisco, Cal.
JONES, PHILIP C., Electrical Engineer, Goodyear Tire & Rubber Co. of California, Los Angeles, Cal.
KEARNS, J. EDWARD, Electrical Engineer, General Electric Co., Chicago, Ill.
KELLEY, WILL G., Overhead Engineer, Commonwealth Edison Co., Chicago, Ill.
LEACOCK, GEORGE D. Y., Sales Manager, Moloney Electric Co. of Canada, Ltd., Toronto, Ont.
MEYERHERM, CHARLES F., Engineer, Albert F. Ganz, Inc., New York, N. Y.
MOLONEY, T. O., President Moloney Electric Co., St. Louis, Mo.
PATTERSON, JAMES G., Staff Engineer, New England Tel. & Tel. Co., Boston, Mass.
RICKWOOD, HAROLD A., Works Manager, Pirelli General Cable Works Ltd., Western Shore, Southampton, England.
SCHIRTZINGER, LEO, District Manager, Century Electric Co., Cincinnati, O.
SPEIGHT, HERBERT, Superintendent of Power, Granby Consolidated Mining, Smelting & Power Co. Ltd., Anyox, B. C.
WEBER, CORNELIUS, G., Assistant Engineer, Vaughn & Meyer, Milwaukee, Wis.
YOUNG, ROWLAND L., Power Engineer, Dept. of Development & Research, American Tel. & Tel. Co., New York, N. Y.
ZEHR, VRATISLAV A., Consulting, Designing, and Constructing Engineer, Pekin, Ill.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1921.

Abel, Lloyd C., Camden, Ark.
Adams, Calvin J., (Member), Syracuse, N. Y.
Adrianson, Gus W., Chicago, Ill.
Alexander, John P., New York, N. Y.
Allen, George A., Portland, Ore.
Anderson, Cedric S., Pittsburgh, Pa.
Ashbaugh, John H., E. Pittsburgh, Pa.
Asplund, J. W., Marshfield, Ore.
Atherton, George V., E. Pittsburgh, Pa.
Atlas, Louis, New York, N. Y.
Austin, Bascum O., E. Pittsburgh, Pa.
Babcock, David L., Oakland, Cal.
Bachman, Harold E., Newark, N. J.
Back, Ashley P., Ft. Wayne, Ind.
Backer, Willis, New York, N. Y.
Bailey, Eugene T., Mexico City, Mex.
Ballard, Harry D., New York, N. Y.
Ballard, Howard A., Asheville, N. C.
Bank, John C., Newark, N. J.
Barger, Ralph H., Rochester, N. Y.
Barnes, Albert K., New York, N. Y.
Barr, George R., Springfield, Mass.
Bartmess, Meigs W., (Member), Cleveland, Ohio
Bean, Roscoe D., Bethlehem, Pa.
Beane, Harry E., Waterbury, Conn.
Beard, Ralph W., Warren, Ohio
Beatty, Lowell D., E. Pittsburgh, Pa.
Beckett, Kenneth C., Bloomfield, N. J.
Belmont, Arthur R., Boston, Mass.
Bengston, Bengt A., Brooklyn, N. Y.
Bensi, Reynold J., Schenectady, N. Y.
Bingham, Sidney, New York, N. Y.
Bjorkhund, John B., Boston, Mass.
Black, Homer S., (Member), New York, N. Y.
Blake, Fred A., Worcester, Mass.
Blevins, Leonard C., Newark, N. J.
Bloomer, Allen T., Hackensack, N. J.
Boden, Walter A., Harrison, N. J.
Bonz, Henry J., Chicago, Ill.
Bourath, J. W., Bayonne, N. J.
Bouton, Edgar M., E. Pittsburgh, Pa.
Bowditch, Fred T., Lakewood, Ohio
Boyd, James, New York, N. Y.
Boyd, Walter W., Washington, D. C.
Branson, David E., New York, N. Y.
Brehm, Clair V., E. Pittsburgh, Pa.
Brothers, George W., New York, N. Y.
Brown, David S., New York, N. Y.
Brown, Walter V., New York, N. Y.
Browning, Jesse O., Russellville, Ky.
Buckley, James L., San Francisco, Cal.
Burgdorfer, Charles L., St. Louis, Mo.
Burgess, Harry J., Baltimore, Md.
Burka, Ferdinand G., Detroit, Mich.
Burns, Archibald E., Portland, Ore.
Burris, Harry L., Pittsburgh, Cal.
Buttrick, Fred A., New York, N. Y.
Byberg, Gustav, Milwaukee, Wis.
Cain, Reuben E., Chicago, Ill.
Cannizzo, Mario, Milwaukee, Wis.
Carroll, Phil, Jr., E. Pittsburgh, Pa.
Carter, Franklin W., E. Pittsburgh, Pa.
Case, Louis M., Irvington, N. J.
Cates, William D., Atlanta, Ga.
Caverly, Harry C., New York, N. Y.
Chalmers, Percy, Niagara Falls, So., Ont.
Chubb, Chester N., Davenport, Ia.
Church, Frederic P., W. Lynn, Mass.
Clarke, Ralph S., Boston, Mass.
Coe, Clarence H., Tillamook, Ore.
Cole, Herbert A., Jr., Boston, Mass.
Cole, J. Foster, Boston, Mass.
Cole, James L., Newark, N. J.
Collier, Charles A., (Member), Atlanta, Ga.
Colson, Henry L., E. Pittsburgh, Pa.
Colson, Wilbur G., Granit City, Ill.
Cone, William L., Salt Lake City, Utah
Conine, Peter D., (Member), Newark, N. J.
Cook, Jesse A., Chicago, Ill.
Cook, William A., Bloomfield, N. J.
Cooper, Thomas, Jr., Boston, Mass.
Cordiner, Neil E., E. Pittsburgh, Pa.
Corey, Norman W., Canton, Ohio
Corliss, Louis F., Brooklyn, N. Y.
Cornell, Harold J., Rutherford, N. J.
Costa, Francisco V., E. Pittsburgh, Pa.
Couch, Ralph T., Liverpool, Ohio
Coughlin, James E., Jr., Chicago, Ill.
Craddock, Don C., Portland, Ore.
Cramer, Harry P., Portland, Ore.
Crawford, Howard I., (Fellow), Wausau, Wis.
Crosse, Claude StC., Ontario, Can.
Crossett, Gordan W., New York, N. Y.
Crowdes, George J., Cambridge, Mass.
Cunningham, Firmin M., St. Louis, Mo.
Curley, John A., Augusta, Ga.
Czachurski, Anthony B., Milwaukee, Wis.
D'Almaine, Harry, Chicago, Ill.
Danis, Norman F., Washington, D. C.
Davies, Stuart R., Sacramento, Cal.
Davis, Harold G., Chicago, Ill.
Dawson, Edward B., E. Pittsburgh, Pa.
Dawson, John E., Detroit, Mich.
Daza, Alvaro, E. Pittsburgh, Pa.
De Dominicis, Vincent, New York, N. Y.
Dehle, Thelma I., E. Pittsburgh, Pa.
Delaney, Ambrose, Hiawatha, Utah
Derby, Ralph W., Mobile, Ala.
Desmond, John J., New York, N. Y.
Dessar, Delwyn, New York, N. Y.
Dibble, Harry H., Detroit, Mich.
Dickerson, Harry M., Annapolis, Md.
Diefendahl, Henry O., New York, N. Y.
Diefenderfer, Ira C., New York, N. Y.
Diehl, Clark E., Harrisburg, Pa.
Doutrick, L. K., E. Pittsburgh, Pa.
Dresslar, Frank A., Portland, Ore.
Drummond, Alfred H., Stamford, Conn.
Dudley, Paul F., Hyde Park, Mass.
Duenke, George A., St. Louis, Mo.
Duncan, Herbert J., Cowley, Wyoming
Eames, William F., E. Pittsburgh, Pa.
Echobs, Joseph, E. Pittsburgh, Pa.
Edwards, Carl F., St. Louis, Mo.
Eissman, James R., E. Pittsburgh, Pa.
Ellenberg, Theo. R., Long Island City, N. Y.
Elmore, Lynden L., E. Pittsburgh, Pa.
Eltz, George J., Jr., (Member), New York, N. Y
Evans, Robert D., E. Pittsburgh, Pa.
Everest, Ernest L., Vancouver, Wash.

Everest, Raymond J., Shawinigan Falls, Que.
Ewart, Archibald McO., Toronto, Ont.
Ewing, Russell P., Woodhaven, L. I.
Fajans, Irving J., New York, N. Y.
Falls, Chester W., Schenectady, N. Y.
Ferguson, Francis G., W. Lynn, Mass.
Ferguson, George F., New York, N. Y.
Ferrin, Ernest W., Manchester, N. H.
Fink, Gustave, Brooklyn, N. Y.
Fochs, Herbert N., New York, N. Y.
Ford, Edward J., E. Pittsburgh, Pa.
Foulkrok, Raymond, New York, N. Y.
Francis, J. Lorton, New York, N. Y.
Fukuskima, Iwao, Minneapolis, Minn.
Galyon, Earl E., E. Pittsburgh, Pa.
Gamble, L. M., Madison, Ill.
Garman, Frank R., Pittsburgh, Pa.
Garthorne, George E., Sacramento, Cal.
Gemmel, Kenneth S., Markdale, Ont.
Gibbon, William R., Los Angeles, Cal.
Gifford, F. L., (Member), Portland, Ore.
Gilbert, Howard D., Worcester, Mass.
Gill, William H., Jr., Newark, N. Y.
Goetze, Alexander P., New York, N. Y.
Goll, Arthur W., Detroit, Mich.
Goodman, Shirley H., Portland, Ore.
Gove, Charles M., New York, N. Y.
Graff, John T., Washington, D. C.
Graham, Ralph W., New York, N. Y.
Granville, William A., Phoenix, Ariz.
Greene, George S., New York, N. Y.
Greenwood, Phil P., Washington, D. C.
Griem, Harvey, W. Allis, Wis.
Grubbs, Grover C., Howell, Mich.
Gushue, George W., E. Pittsburgh, Pa.
Gustafson, Gustaf H., Beaver Falls, Pa.
Haas, Henry, Jackson, Mich.
Halt, Arthur B., Medford Hillside, Mass.
Hambleton, Thomas T., Schenectady, N. Y.
Handerwick, Reginald G., Swampscott, Mass.
Hastings, Allen, Big Creek, Cal.
Hawley, Kenneth F., Baltimore, Md.
Haynes, Walter, Portland, Ore.
Hecksher, Sigurd H., Pueblo, Mexico
Hedley, Walter J., New York, N. Y.
Heidrich, Herman C., Newark, N. J.
Hellborn, Axel V., (Member), New York, N. Y.
Henkel, Ferd, Portland, Ore.
Hennel, Elek, New York, N. Y.
Hess, John E., Peterboro, Ont.
Higson, Charles R., Salt Lake City, Utah
Hildebrand, Lee E., (Member), Lynn, Mass.
Hildum, Charles E., New York, N. Y.
Hill, Everett D., New York, N. Y.
Hill, John F., St. Catharines, Ont.
Hill, William E., Geneseo, N. Y.
Hirose, Yoshitomo, New York, N. Y.
Hodgkins, Roger E., E. Pittsburgh, Pa.
Hodgson, Alfred I., Ontario, Can.
Hofmann, Henry F., New York, N. Y.
Holl, Robert E., New York, N. Y.
Holmgren, Viking R., Lynn, Mass.
Holy, Clarence G., Schenectady, N. Y.
Hooper, John A., Portland, Ore.
Horner, Fred S., Milwaukee, Wis.
Houck, Harry W., New York, N. Y.
Hovey, Frank A., Boston, Mass.
Howard, John J., (Member), New Haven, Conn.
Hubbs, Horace N., Montour Falls, N. Y.
Hyatt, William R., Toronto, Ont.
Irwin, John B., New York, N. Y.
Jaeckel, Walter L., Cleveland, Ohio
Jeep, Edward J., St. Louis, Mo.
Jennings, Aaron F., Pittsfield, Mass.
Jensen, Gunnar, E. Pittsburgh, Pa.
Jett, William B., Portland, Ore.
Johnson, Alan H., Helena, Mont.
Johnson, Arnold R., Milwaukee, Wis.
Johnson, Lester B., Salt Lake City, Utah
Johnson, Robert H., Portland, Ore.
Johnson, Samuel E., Aurora, Ill.
Johnson, Walter E., Hibbing, Minn.
Jomini, Samuel, Jr., Grand Mere, Que.
Jones, Clarence E., Toledo, Ohio
Jones, James K., E. Pittsburgh, Pa.
Jones, Warren C., New York, N. Y.
Jordan, Charles A., New York, N. Y.
Kahn, Jacob A., Salt Lake City, Utah
Kaufman, Joseph, Williamsport, Pa.
Kellaway, Garnet, Toronto, Ont.
Kelly, Charles J., San Luis Obispo, Cal.
Kelly, James, Jackson, Mich.
Kelm, Alfred C., Grace, Idaho
Kenyon, J. T. P., New York, N. Y.
Kilian, James M., E. Pittsburgh, Pa.
King, Harry M., Niagara Falls, Ont.
Kintzing, R. Tench, (Member), E. Pittsburgh, Pa.
Kirk, Arthur S., Boston, Mass.
Kissinger, J. Herbert, Reading, Pa.
Knowles, Charles S., Kennewick, Wash.
Koechel, Walter P., Bogota, N. J.
Koester, Frederick A., San Francisco, Cal.
Korfhage, H. G., New York, N. Y.
Kotrbaty, Guy F., New York, N. Y.
Krieger, Charles A., Rochester, N. Y.
Kronenberg, John F., Bandon, Ore.
Krouse, William F., New York, N. Y.
Kruz, Jack, Chicago, Ill.
Kuykendall, William R., Portland, Ore.
Kvake, Torgeir K., New York, N. Y.
Lanfair, Walter A., Springfield, Mass.
Lang, Richard H., Baltimore, Md.
Laurie, Russell McL., Niagara Falls, Ont.
Lavelle, John R., Naturita, Colo.
La Vigna, William, Cleveland, Ohio
Lee, Stanley, E. Pittsburgh, Pa.
Lender, Gustave F., Detroit, Mich.
Leonard, George W., Lancaster, Pa.
Lester, R. Verne, Wilkinsburg, Pa.
Levis, John H., Jr., Rochester, N. Y.
Lewis, Frank E., E. Pittsburgh, Pa.
Lewis, Stanley M., Ft. Wayne, Ind.
Lillie, Gerald L., Toronto, Ont.
Limbocker, Wayne E., Kansas City, Mo.
Lincoln, John G., Cleveland, Ohio
Lind, W. Earl, Wilmington, Del.
Lu, Wen Siang, Boston, Mass.
Lunn, Arthur W., (Member), Newark, N. J.
MacCallum, Clarence, (Fellow), New York, N. Y.
MacFadden, Vernon, E. Pittsburgh, Pa.
Mackey, Paul R., Montour Falls, N. Y.
MacLean, Donald, Brooklyn, N. Y.
McLean, Arthur M., Portland, Ore.
McLean, Charles C., Portland, Ore.
MacNaughton, Archibald K., Pawtucket, R. I.
Mahon, Arthur A., Ft. William, Ont.
Mahoney, William L., Jackson, Mich.
Maidment, William, Elizabeth, N. J.
Mangles, Rudolph H., Jersey City, N. J.
Manwaring, Roy A., (Member), Seward, Pa.
Markle, Lewis E., E. Pittsburgh, Pa.
Massie, Arnold C., New York, N. Y.
Matthews, Charles H., E. Pittsburgh, Pa.
Maxfield, Harold A., E. Pittsburgh, Pa.
McAllister, James H., (Member), Cambridge, Mass.
McGee, P. A., (Member), E. Pittsburgh, Pa.
McIntire, Edgar F., Baltimore, Md.
McKee, Amos S., Chicago, Ill.
McWherter, Miles C., Pittsburgh, Pa.
McWhirk, Theodore H., Atlanta, Ga.
Menawell, Charles V., Detroit, Mich.
Merchant, Dorsey W., Ft. Wayne, Ind.
Merkel, Frederick W., New York, N. Y.
Merritt, Robert W., Los Angeles, Cal.
Merwin, Harry E., Portland, Ore.
Mestler, William H., Rochester, N. Y.
Miller, Charles A., New York, N. Y.
Miller, Frank S., New York, N. Y.
Miller, Robert, Salt Lake City, Utah
Minor, Henry S., Fresno, Cal.
Mirick, Harry L., New York, N. Y.
Monahan, James B., New York, N. Y.
Montgomery, W. B., Appleton, Wis.
Moore, John M., Schenectady, N. Y.
Morgan, Charles H., (Member), Humboldt, Iowa
Morgan, John P., Toronto, Ont.
Morrell, John H., E. Pittsburgh, Pa.
Moss, J. Mora, J., San Francisco, Cal.
Moyer, Harry M., Erie, Pa.
Mueller, Ernest R., Queens, L. I.
Muirhead, James, Vancouver, B. C.
Mullen, Thomas H., Leavenworth, Wash.
Munoz, Leopoldo G., Queretaro, Qro., Mexico
Murnan, Jeremiah A., New York, N. Y.
Murphy, Thomas B., E. Pittsburgh, Pa.
Murray, Edmund W., Toronto, Ont.
Myers, Jesse L., Toledo, Ohio
Nedra, Ian I. W., Irwin, Pa.
Nicholson, Frank C., (Member), Wilkes-Barre, Pa.
Niedringhaus, William F., Granite City, Ill.
Nott, Harry E., (Fellow), Monroe, Wis.
Ochiltree, William H., Pittsburgh, Pa.
Odell, Herbert J., Boston, Mass.
Ohl, William F., New York, N. Y.
O'Keefe, Daniel F., Brooklyn, N. Y.
Olson, O. V., Emeryville, Cal.
O'Neel, Clarence M., Latouche, Alaska
Paesel, Carl M., Chicago, Ill.
Panter, John S., Toronto, Ont.
Parks, Fred M., E. Pittsburgh, Pa.
Pascarello, Anthony J., Woodridge, N. J.
Pascoe, Wilbur, Detroit, Mich.
Patterson, Frederick S., Hempstead, N. Y.
Paul, R. J., St. Louis, Mo.
Peach, Thomas H., Grand Mere, Que.
Pehrson, Alphonse A., New York, N. Y.
Perrin, James A., Cumberland, Md.
Perry, Tom, Portland, Ore.
Petrik, John J., Detroit, Mich.
Pettengill, George W., E. Pittsburgh, Pa.
Philip, William M., Niagara Falls, So., Ont.
Pierce, Donald A., Chicago, Ill.
Pieper, Arthur R., Chicago, Ill.
Pikas, Joseph G., Chicago, Ill.
Pippenger, H. F., Wilkinsburg, Pa.
Plimpton, Charles G., Waltham, Mass.
Plummer, Clifford R., Indianapolis, Ind.
Portejoie, Georges P., Shawinigan Falls, Que.
Post, Welles M., Pittsburgh, Pa.
Powers, Clifford F., Cleveland, Ohio
Preston, Chauncey D., Pittsfield, Mass.
Priddle, William H., Toronto, Ont.
Quaas, Richard T., New York, N. Y.
Quentin, George W., (Member), Pittsburgh, Pa.
Quigley, Ray L., Toledo, Ohio
Quimby, Malcolm J., Ft. Wayne, Ind.
Quirin, George E., Calgary, Alberta, Can.
Randall, Arthur T., E. Pittsburgh, Pa.
Rapp, Stanley, San Francisco, Cal
Reagan, Leon S., Mason City, Iowa
Reding, Henry W., Atlanta, Ga.
Redman, Joseph R., Brooklyn, N. Y.
Rehfield, Edward G., New York, N. Y.
Reiter, Cryma A., New York, N. Y.
Renaud, Eugene S., Chicago, Ill.
Rheingold, Leo C., New York, N. Y.
Rice, Harry J., New York, N. Y.
Rice, James F., Chicago, Ill.
Richardson, Stanley M., (Member), Toronto, Ont.
Richardson, Walter E., Bowman, Cal.
Riley, Clarence L., Atlanta, Ga.
Roberts, Claudius, H. M., Washington, D. C.
Roberts, Lester W., Milwaukee, Wis.
Rodgers, Ralph C., New York, N. Y.
Rosaler, Akim, New York, N. Y.
Ruggles, Leonard L., Chicago, Ill.
Sacco, Emile J., E. Pittsburgh, Pa.
Sanders, Thornton E., Portland, Ore.
Sayre, Earl E., Schenectady, N. Y.
Schloetzer, Fred E., Kearny, N. J.
Scott, L. Wilson, (Member), Charleston, W. Va.
Seacord, Kenneth P., New York, N. Y.
Seibel, Andrew E., New York, N. Y.
Shaffer, Stanley, Cincinnati, Ohio
Sharp, Wilbur L., Portland, Ore.
Shaw, George R., E. Pittsburgh, Pa.
Shaw, Michael G., E. Pittsburgh, Pa.
Shogren, Thomas E., E. Pittsburgh, Pa.
Shrader, James E., E. Pittsburgh, Pa.
Shultz, Adie D., Salisbury, Md.
Shumway, Loren F., E. Pittsburgh, Pa.
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Simmons, Frank, Woonsocket, R. I.
Simons, Walter W., Newark, N. J.
Sipher, Edmund F., E. Pittsburgh, Pa.
Skyberg, Trygve T., Perth Amboy, N. J.
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Smith, Alanson F., Milwaukee, Wis.
Smith, Charles W., San Francisco, Cal.
Smith, Joseph F., Shawinigan Falls, Que.
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Sullivan, Richard W., Boston, Mass.
Swartz, Will E., Dunnville, Ont.
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Tardy, Leo H., Washington, D. C.
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Thomas, Harold P., Cleveland, Ohio
Thomas, J. I., York, Pa.
Thompson, Harold W., Worcester, Mass.
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Tilson, Waller, Indianapolis, Ind.
Timmins, Walter J., Orange, N. J.
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Unangst, Earle G., New York, N. Y.
Van Hook, L. N., St. Louis, Mo.
Van Steenburgh, W. R., New York, N. Y.
Van Winkle, Frank H., New York, N. Y.
Walker, Harry C., Atlanta, Ga.
Walls, Ray B., Portland, Ore.
Waters, James S., Jr., Houston, Texas
Weatherall, Eley, Portland, Ore.
Webb, Loren G., Eau Claire, Wis.
Weeks, Walter H., New York, N. Y
Wells, Ward E., Holtwood, Pa.
Westerfield, Milo H., Elizabeth, N. J.
Weston, Cyril L., Montreal, Que.
Weyandt, Albert C., E. Pittsburgh, Pa.
Whealy, Wilfred, E. Pittsburgh, Pa.
Wheatley, Russell G., Schenectady, N. Y.
Wheeler, Paul V., Cleveland, Ohio
Wilke, Max, Steubenville, Ohio
Wilkins, Malcolm L., Dover, N. H.
Willard, Sherwood H., New York, N. Y.
Willmann, William F., Boston, Mass.
Wilson, Charles H., E. Pittsburgh, Pa.
Wimmer, Joseph, Seattle, Wash.
Winemiller, Price L., Kansas City, Mo.
Wolff, Boyd L., Portland, Ore.
Woods, William H., Toronto, Ont.
Worley, Ivan H., International Falls, Minn.
Wortham, Henry, Jr., Chicago, Ill.
Wright, Harry H. L., Montour Falls, N. Y.
Wyatt, Joseph A., Hempstead, N. Y.
Yost, Charles Z., San Francisco, Cal.
Ziehl, William J., New York, N. Y.
Zinter, Jules A., Indianapolis, Ind.
Zobel, Maurice L., Brooklyn, N. Y.
Total 461

Foreign

Elphick, Cyril M. V., Manchester, Eng.
Hale, L. H., E. Hartford
Iida, Atsushi, Osaka, Japan
Maristany, Gabriel, Havana, Cuba
Oaten, Herbert C., Auckland, N. Z.
Otto, Georg E., Dresden, Germany
Perez, Jose L., Barcelona, Spain
Seto, Shoji, Tokyo, Japan
Snow, Percy E., Ancon, C. Z.
Yamada, Hideo, Tokyo, Japan
Yanagiwara, Saijiro, Oita City, Kyushu, Japan
Total 11

STUDENTS ENROLLED FEBRUARY 16, 1921

12672 Ringel, Robert I., Cooper Union
12673 Morell, Nicholas G., Penn. State College
12674 Litch, Richard C., New Hampshire College
12675 Langford, John A., University of Toronto
12676 Campbell, Thomas L., Univ. of Toronto
12677 Wells, Ralph M., Johns Hopkins Univ.
12678 Bazilevitch, Leonid, Carnegie Institute o Technology.
12679 Mahle, Herbert J., Johns Hopkins Univ.
12680 Cohn, Michael, Johns Hopkins University
12681 Bowman, John D., Mass. Institute of Tech.
12682 Jenney, Melvin R., Mass. Inst. of Tech.
12683 Clark, Harry F., University of Cincinnati
12684 Fuehrer, Lewis M., Pennsylvania State College
12685 Hetznecker, Joseph R., Penn. State College
12686 Taylor, Colin A., Univ. of Washington
12687 Kamphausen, Rudolph C., University of Cincinnati
12688 Jackson, Frederick D., Penn. State College
12689 Rusch, Hugo L., University of Wisconsin
12690 Locke, Ben N., Cornell University
12691 Kippner, Philip G., School of Engineering of Milwaukee
12692 McFarlan, James P., Univ. of Cincinnati
12693 Fries, G. Park, Case School of Applied Sci.
12694 Settles, Orval P., Case School of Applied Science
12695 Bowers, Clarence, Case School of Applied Science
12696 Havens, Harry B., Case School of Applied Science
12697 Gray, Max L., Univ. of Washington
12698 Gough, Hugh F., Pennsylvania State Coll.
12699 Wiegand, Vernon I. E., Univ. of Cincinnati
12700 Pigman, Samuel S., Penn. State College
12701 Floyd, Dewey A., North Carolina State Col.
12702 Clinedinst, Wendel W., Stevens Institute of Technology.
12703 Greear, Howard B., Virginia Poly. Inst.
12704 Guillemin, Ernst, University of Wisconsin
12705 Taranger, Aksel, University of Wisconsin
12706 O'Brien, Frederic L., Carnegie Institute of Technology
12707 Stover, James R., Penn. State College
12708 Rockwood, Alan C., State University of Ia.
12709 Chapman, Robert L., Kansas State Agricultural College
12710 Hallman, Ralph L., Penn. State College
12711 Neller, H. F., Tri-State College
12712 Hyneman, John R., Purdue University
12713 Winans, Denward M., Purdue University
12714 LeFavour, Lawrence G., Purdue University
12715 Yelton, Carey M., Purdue University
12716 Sheppard, Ernest J., Purdue University.
12717 Anders, Russell H., Purdue University
12718 Spaulding, George H., Purdue University
12719 Gohlke, Arthur C., Purdue University
12720 Deller, Russel A., Purdue University
12721 Lightfoot, F. A., Purdue University
12722 Showalter, John M., Purdue University
12723 Crabtree, Edgar G., Purdue University
12724 Page, Karl J., Marquette University
12725 Carl, Willington C., Carnegie Inst. of Tech.
12726 Baumback, George E., Marquette Univ.
12727 Thomas, Farnum E., Clemson College
12728 Miley, L., Clemson College
12729 O'Neill, Bernard, Clemson College
12730 Harden, William R., Clemson College
12731 Rosa, J. R., Clemson College
12732 Epting, Carl V., Clemson College
12733 Spearman, James H., Clemson College
12734 Stauffer, Burton C., Penn. State College
12735 Jensen, Miels, P., Pratt Institute
12736 Ford, Henry R., New Hampshire College
12737 Christopher, Arthur J., Carnegie Institute of Technology
12738 Bieter, Walter A., School of Engineering of Milwaukee
12739 Walter, James R., Penn. State College
12740 Lubic, Herman M., Penn. State College
12741 Maxson, Raymond D., University of Ill.
12742 Burtis, William K., School of Engineering of Milwaukee
12743 Stranathan, James D., University of Kansas
12744 Marx, Leo G., Marquette University
12745 De Haye, Joseph F., Marquette University
12746 Gibbons, John J., Marquette University
12747 Kattenhauser, Charles C., Carnegie Institute of Technology
12748 Overbaugh, Fred, Pratt Institute
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12750 Rosenbloom, Max A., Carnegie Institute of Technology
12751 Keller, William A., Carnegie Institute of Technology
12752 Kakilty, Arthur W., Carnegie Inst. of Tech.
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12761 Walker, Charles P., California Institute of Technology
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12763 Rusk, Alexander P., Johns Hopkins Univ.
12764 Shank, James S., Johns Hopkins University
12765 Oglebay, William J., Johns Hopkins Univ.
12766 Perlman, David L., Johns Hopkins Univ.
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12769 Williams, O. D., Alabama Polytechnic Inst.
12770 Smith, Charles A., Alabama Poly. Inst.
12771 Fullwood, Harry S., Jr., Alabama Polytechnic Institute
12772 Holt, James F., Alabama Polytechnic Inst.
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12784 Zuelow, Felix W., School of Engineering of Milwaukee
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12786 Walters, Chauncey R., Penn. State College
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12791 Meyer, William G., Drexel Institute
12792 Kothlow, Thaddeus O., School of Engineering of Milwaukee
12793 Hodson, John R., Virginia Polytechnic Inst.
12794 Scott, Horace S., Virginia Polytechnic Inst.
12795 Wirt, William O., Virginia Polytechnic Inst.
12796 Copenhauer, John K., Virginia Polytechnic Institute
12797 Hornbarger, Earl H., Virginia Polytechnic Institute
12798 Bailey, Robert C., Virginia Polytechnic Institute
12799 Gregory, Charlie, Virginia Polytechnic Inst.
12800 Ryman, Jacob F., Virginia Polytechnic Inst.
12801 Painter, Benjamin D., Virginia Polytechnic Institute
12802 Schatz, Nathan, Tufts College
12803 Anderson, Claire A., Univ. of Pittsburgh
12804 Schwartz, Philip Princeton University
12805 Wald, Gerson E., New York Electrical Sch.
12806 Polley, Irving F., Wentworth Institute
12807 Wolfinger, Ralph W., Univ. of Cincinnati
12808 Haslup, DeWilton W., Johns Hopkins Univ.
12809 Stolworthy, Frank H., Tufts College
12810 Fuller, George B., University of Toronto
12811 McHaffie, Roy P., University of Toronto
12812 Morris, Robert S., Toronto Central Technical School
12813 Sparrow, Arthur L., Toronto Central Technical School

12814 Reilly, Edward L., Carnegie Institute of Technology
12815 Kurth, Henry L.R., Mass. Institute of Tech.
12816 Oliver, Francis J., Jr., Stevens Institute of Technology
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12819 Haskins, Lawrence E., Tufts College
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12821 Paschal, Robert S., Georgia School of Tech.
12822 Radford, Robert P., Georgia School of Tech.
12823 Short, Will B., Georgia School of Tech.
12824 Young, Roy C., Georgia School of Tech.
12825 Miller, Laurence S., Georgia School of Tech.
12826 Williams, W. LeRoy, Georgia School of Tech.
12827 Taylor, Clyde A., Jr., Georgia School of Tech.
12828 Allen, Ernest W., Georgia School of Tech.
12829 Waldrop, Guy, Georgia School of Tech.
12830 Peteet, William D., Georgia School of Tech.
12831 Patterson, William F., Georgia School of Tech.
12832 Frankum, Jay L., Georgia School of Tech.
12833 Fort, James A., Jr., Georgia School of Tech.
12834 Merritt, Edward H., Georgia School of Tech.
12835 Almond, Edwin P., Georgia School of Tech.
12836 Adams, Charles C., Georgia School of Tech.
12838 Greene, Asbury B., Jr., Georgia Sch. of Tech.
12839 Howell, Edwin H., Georgia School of Tech.
12840 Thomson, Mark F., Georgia School of Tech
12841 Mundy, Ivy LaN., Georgia School of Tech.
12842 Matheson, Donald J., Georgia Sch. of Tech.
12843 Mobley, John H., Georgia School of Tech.
12844 Campbell, William W., Georgia Sch. of Tech.
12845 Salisbury, Thomas M., Georgia Sch. of Tech.
12846 Palin, Adolphus W., Jr., Georgia Sch. of Tech.
12847 LeBey, Christian D., Georgia School of Tech.
12848 Phillips, Dexter W., Georgia School of Tech.
12849 Stevens, Chandler H., Georgia Sch. of Tech.
12850 Rose, Albert W., Georgia School of Tech.
12851 Getzen, John E., Georgia School of Tech.
12852 Anderson, George D., Jr., Georgia School of Technology
12853 Montgomery, Terry B., Georgia Sch. of Tech.
12854 Looper, Glenn, Georgia School of Tech.
12855 Patton, John E., Georgia School of Tech.
12856 Herring, Thomas F., Georgia School of Tech.
12857 Weil, A. Siegmund, Georgia School of Tech.
12858 Harris, Robert D., Georgia School of Tech.
12859 Booth, Walter W., Georgia School of Tech.
12860 Fouche, Dudley, D., Georgia School of Tech.
12861 Rykert, Willard C., Armour Inst. of Tech.
12862 Crane, Webster O., Armour Inst. of Tech.
12863 Thompson, John B., Armour Inst. of Tech.
12864 Love, Harold G., Armour Institute of Tech.
12865 Hoeflinger, Louis J., College of the City of New York
12866 Schulze, Raymond C. R., Carnegie Institute of Technology
12867 Bernstein, Samuel, Johns Hopkins Univ.
12868 Williams, Everett W., Clemson College
12869 Quattlebaum, Charles A., Jr., Clemson Col.
12870 Lind, Louis, Brooklyn Polytechnic Inst.
12871 Russell, Carl, Oregon State Agri. Coll.
12872 Krosjesovies, Ernest G., Carnegie Institute of Technology
12873 Koch, William A., Jr., Drexel Institute
12874 Aulfather, David H., University of Minn.
12875 Downie, John M., University of Minn.
12876 Drost, Henry F., University of Minnesota
12877 Dunnum, O. E., University of Minnesota
12878 Grettum, Walter A., University of Minn.
12879 Olson, Arnim G., University of Minn.
12880 Rome, Robert C., University of Minn.
12881 Lein, Ernest L., Purdue University
12882 Church, Leonard H., Purdue University
12883 Oplinger, Kirk A., Purdue University
12884 Speer, Franklin R., Cornell University
12885 Burke, James H., Cornell University
12886 Taylor, Edward W., Cornell University
12887 Planas, Edward J., New York Electrical Sch.
12888 Irvine, Charles N., Carnegie Institute of Tech.
12889 Day, Clarence C., Tri-State College
12890 Del Home, William E., Alabama Polytechnic Institute
12891 Richford, James E., Tri-State College
12892 Knox, William E., New Hampshire College
12893 Johnson, Subrey N., Tri-State College
12894 Krantz, Walter C., New York Electrical Sch.
12895 Freeman, Harry, Toronto Central School
12896 Carhart, John R., Toronto Central Technical School
12897 Bairstow, Edwin, Toronto Central Technical School
12898 Rowland, Albert, Toronto Central Technical School
12899 McLean, Archibald N., Toronto Central Technical School
12900 McGuire, Donald B., Mass. Institute of Tech.
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A complete list of the 39 Sections and 61 Branches of the Institute, with the names of the chairmen and secretaries, will be found in the January issue of the Journal and will be published again in the June issue.

JOURNAL
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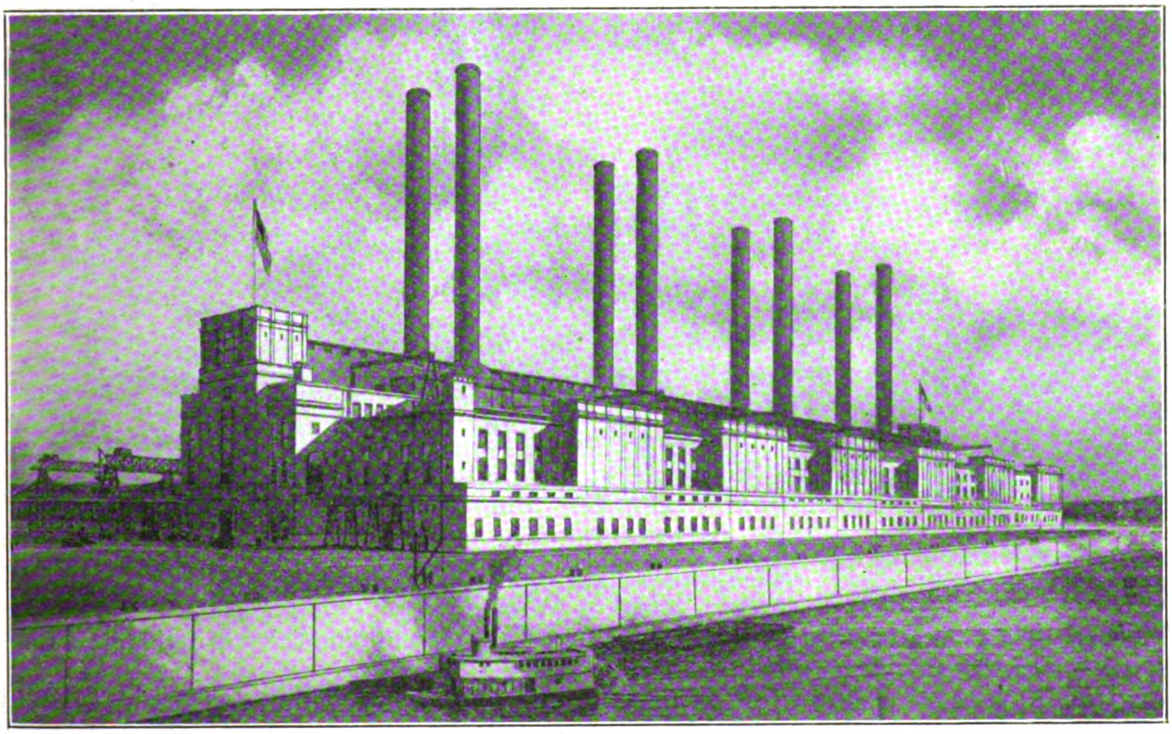
Vol. XL | APRIL, 1921 | Number 4

Colfax Power Station of the Duquesne Light Company Pittsburgh

By D. L. GALUSHA and C. W. E. CLARKE
of Dwight P. Robinson & Company, Inc.

THE PITTSBURGH district is the foremost steel-producing and manufacturing centre in this country. Steel plants with their furnaces and mills line the river banks for miles from the center of the city. Associated industries, attracted by an abundance of natural resources, adequate transportation facilities, ample labor supply, and proximity to markets for their products, have rapidly come into the adjacent territory. Growth during the war period was extensive, and the district as a whole has been busy since hostilities ended. Today, the Pittsburgh district may be fairly called the workshop of the world.



Colfax Power Station—The Ultimate Development

A power station which will utilize, for condensing purposes, the entire minimum flow of the Allegheny River in 300,000 kw. of turbo-generators housed in a building 830 feet long.

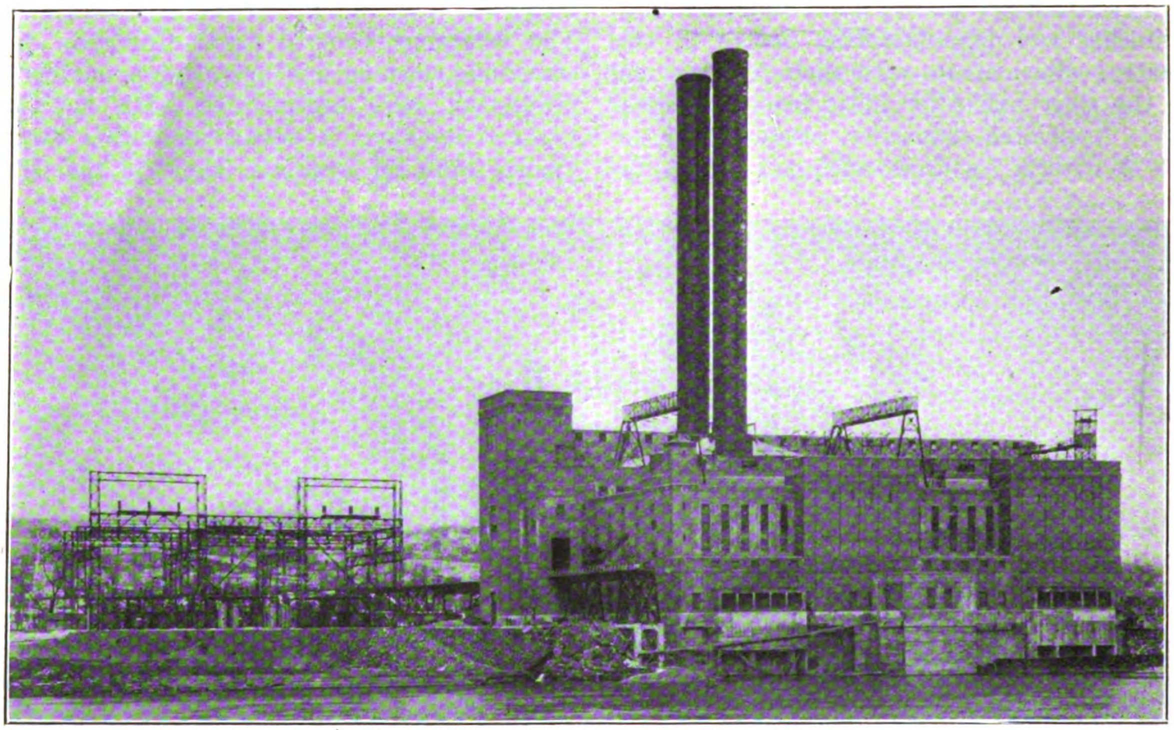
By 1912, central station facilities in the Pittsburgh district had become inadequate to meet the requirements of the rapidly growing industrial demand. The Allegheny County Light Company and other companies, owning and operating a number of small properties, were consolidated with the Duquesne Light Company. A steam-generating station previously built on Brunot's Island in the Ohio River below the city was considerably enlarged and the foundation laid for a comprehensive distribution system.

By an agreement with the West Penn Power Company and with the approval of the Pennsylvania Public Service Commission, a definite division of the territory served by the two companies was effected. The Duquesne Light Company, through this arrangement, serves the two counties—Allegheny and Beaver—with an area of 1154 square miles and a population of about one million and a quarter.

To be presented at the 369th Meeting of the A. I. E. E. in joint session with the A. I. & S. E. E., Pittsburgh, Pa., April 16, 1921.

In 1913, the first year after the formation of the new company, the energy output was 283,000,000 kw-hr. In recent years, the output has shown an average annual growth of about 15 per cent. Last year, the peak, which was somewhat affected by the curtailment of business, was 162,500 kw.; the energy output 805,000,000, kw-hr. giving a yearly load factor of 57 per cent.

Previous to 1921, power was generated at the Brunot's Island station of 120,000 kw. capacity and at six other plants, varying from 2000 to 17,000 kw. in rating. The total generating capacity safely available from all of these sources under maximum conditions is 160,000 kw.



COLFAX POWER STATION—THE FIRST STEP

A building for two 60,000-kw. units. The standard gage railroad entering the northwest corner of the building brings in the coal, and 66,000-volt cables descending from the roof to the steel structure at the west end of the building take the electric energy away.

In anticipation of the need of increased capacity, a site for a new power plant had been purchased. The location selected is on the Allegheny River about 15 miles from the center of Pittsburgh and only a mile distant from the Harwick mine. This mine and the private railroad from it to the power station are owned by interests affiliated with the Duquesne Light Company.

Actual construction of the new plant, known as the Colfax Power Station, was begun in September 1919, and the station was officially opened for service on December 18th, 1920. Transmission line and substation construction was in progress during the same period.

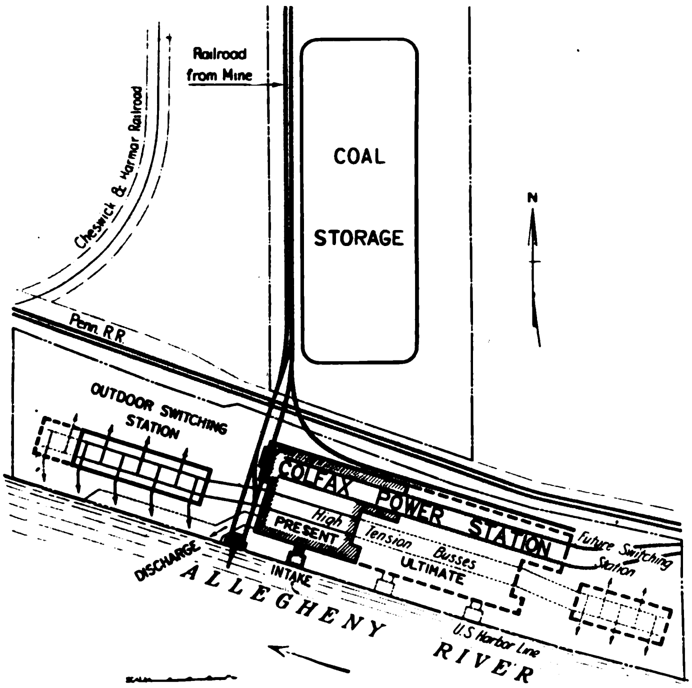
Duplicate 66,000-volt transmission circuits completely surround the city, forming an electric belt locally known as "The Duquesne Ring." The Brunot's Island and Colfax plants are almost diametrically opposite each other in this ring. Substations located at intermediate points and fed from either or both generating stations supply radial 22,000- and 11,000-volt feeders, which, in turn serve other substations and consumers within the industrial district.

In the design of the Colfax plant four major considerations have been kept in view; first, to plan for the largest development which is economical at the site chosen; second, to produce a plant which will generate power at the lowest unit cost, including fixed charges, permitted by the state of the art; third, to obtain the maximum reliability practicable, and fourth, to adopt simplicity of design as a fundamental policy.

The flow of the Allegheny River, upon which the plant depends for condensing water, is found to furnish a natural limitation to the capacity which may be developed at Colfax. The minimum flow of this river is sufficient to furnish condensing water for 300,000 kw., therefore the design is made so that the power station can be extended on a uniform plan until all available condensing water has been utilized. To allow for contingencies and spare equipment a development somewhat beyond the minimum is provided for.

The size of the unit chosen, 60,000 kw. nominal, is such that the ultimate development may be divided into five or six steps and when the plant is completed it will not be complicated with a large number of small units.

The first step of the development which is now completed includes one 60,000-kw. turbine and seven boilers. The power station building is, however, large enough for two units.

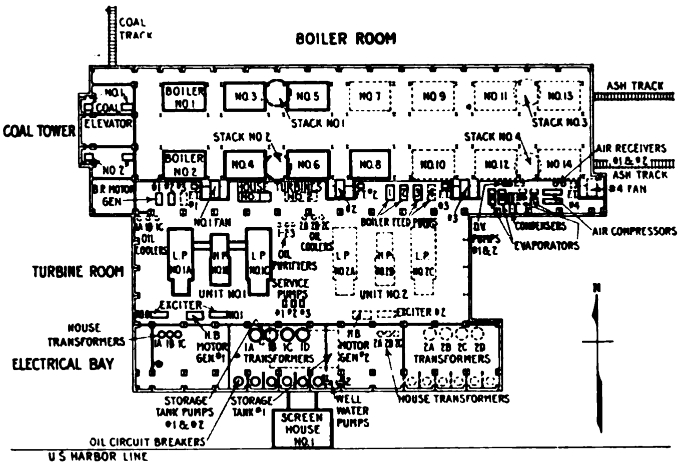


Power Station Lot Plan

This plan shows the relative locations of coal storage, power house and switching station. It also shows the simple and direct paths along which fuel, water and electric current progress on their way through the works.

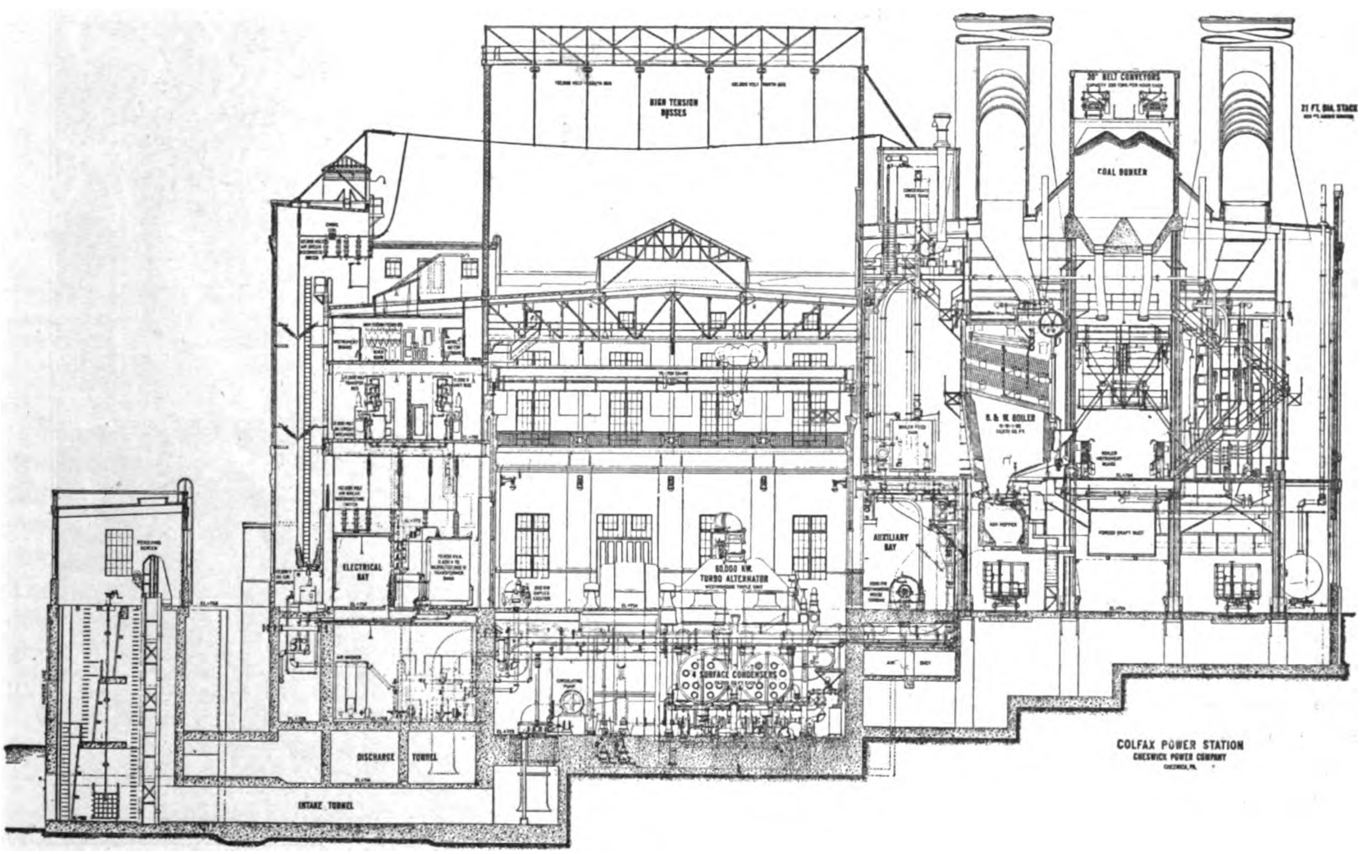
The relative floor spaces occupied by the turbines and the boilers are important factors in the general arrangement of the power station. In this case the turbine room has a width of 84 ft. and the boiler room of 108 ft. which, together with the electrical bay, give a station 240 ft. wide over-all. The boiler room is 350 ft. long and the turbine room is 278 ft. long, giving an approximate balance in length between turbine and boiler room.

A Westinghouse three-cylinder compound turbine



Power Station Floor Plan

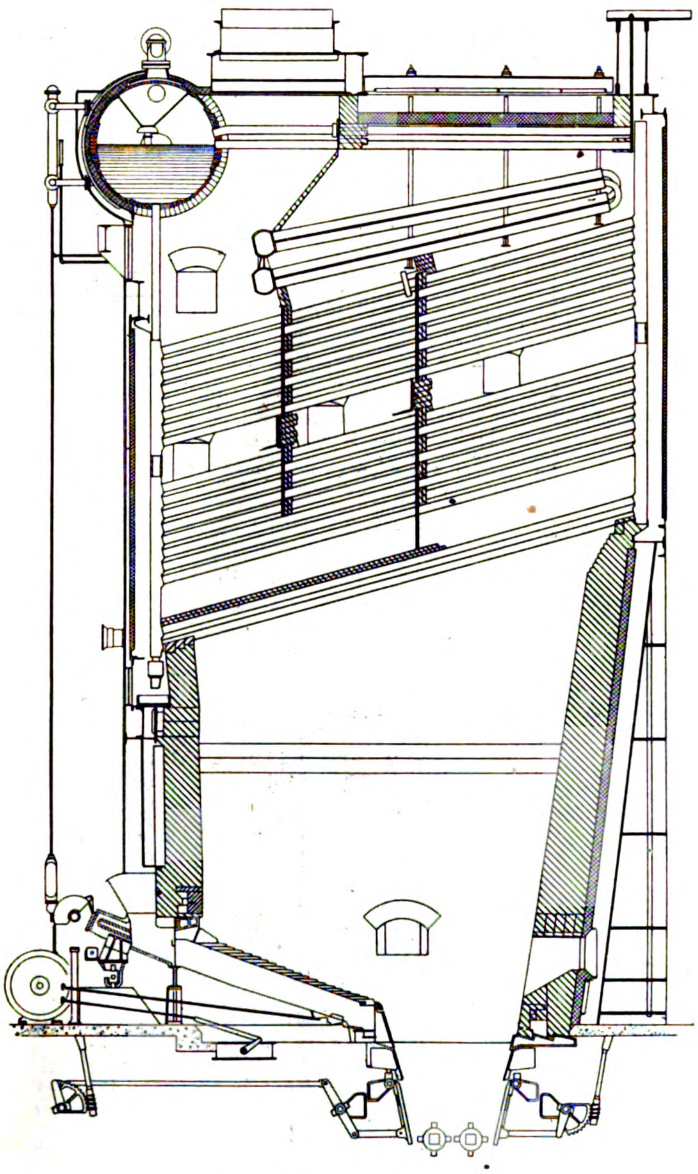
Relative location of boilers, stacks, draft fans, feed pumps, main turbines, house turbines, exciters, heat balance motor-generator, main transformers, house transformers and various auxiliaries.



Cross-Section of Colfax Power Plant

This section indicates the path of the coal from bunker through weighing larry to stoker and of ashes from stoker through ash hopper to railroad car. It also shows the path of the circulating water from intake through screen well, intake tunnel, circulating pumps and condensers to discharge tunnel. The arrangement of the apparatus in the electrical bay is well shown.

has been used. In this machine the expansion of the steam is divided into two steps and the low-pressure steam of the second step is divided into two parts. This division of the work of the steam gives three distinct mechanical elements, one being high-pressure and two low-pressure. These three elements are

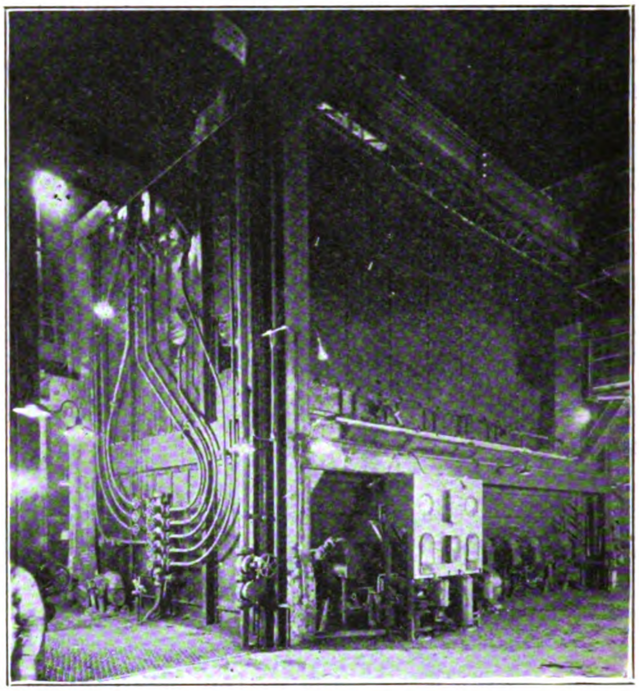


SECTION THROUGH BOILERS

The boilers are 18 tubes high with the two lower rows dropped below the tube bank and exposed to the direct heat of the furnace throughout their whole length. The boilers are set exceptionally high to give a large furnace volume.

logically grouped side by side with parallel shafts with the high-pressure element in the middle and one low-pressure element on each side. With this arrangement each unit occupies a space 50 ft. 10½ in. in the direction of the shafts and 79 ft. 2 in. at right angles to the shafts.

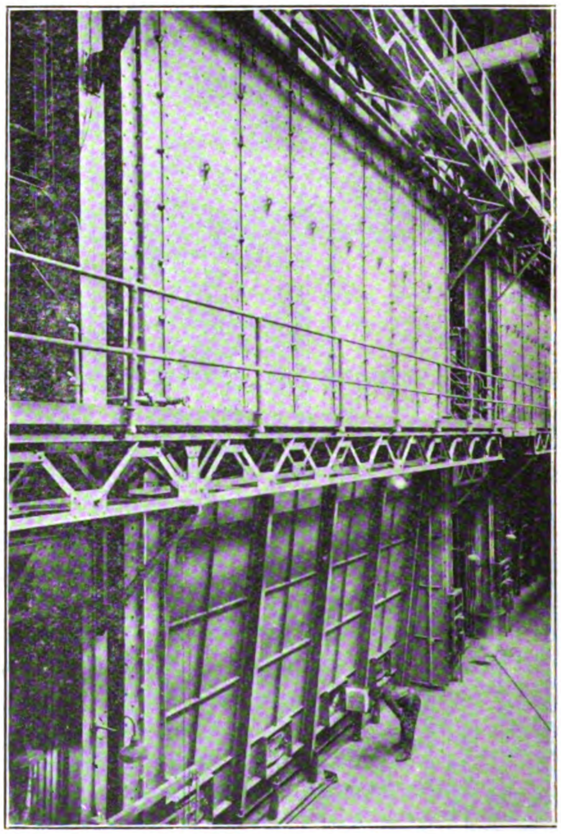
Babcock and Wilcox boilers of the greatest practicable width were selected, each boiler occupying a floor space about 34 ft. wide and 22 ft. from front to back.



COMPLETED BOILER

Illustrates the arrangement of the soot blower piping and its controlling valves, the location of the boiler gage board and the clinker-grinder drive.

With these boilers it has been practicable to use a boiler room with a single firing aisle between a double



REAR OF BOILERS

This view shows rear of south battery of boilers showing walkways on two levels and comparative size of boiler to man in foreground.

row of singly fired boilers, an arrangement which is highly desirable where the relative space occupied by turbines and boilers permits.

The illustrations herewith show the arrangement of the power house in much detail and the capacity and ratings of the important pieces of apparatus are listed in an appendix. A further detailed description is dispensed with in order to permit a discussion of some of the more important considerations which governed the design.

on an elevated trestle and the coal is dumped directly into the power station hoppers from which it passes by gravity to two crushers. The crushed coal is elevated by a bucket carrier to the top of the boiler room and is then distributed to the bunker by two belts with automatic traveling trippers.

The mine furnishes a semi-bituminous coal having a heating value of approximately 13,500 B. t. u. per lb. as received. Provision has been made for systematically testing the quality of the coal by taking a con-

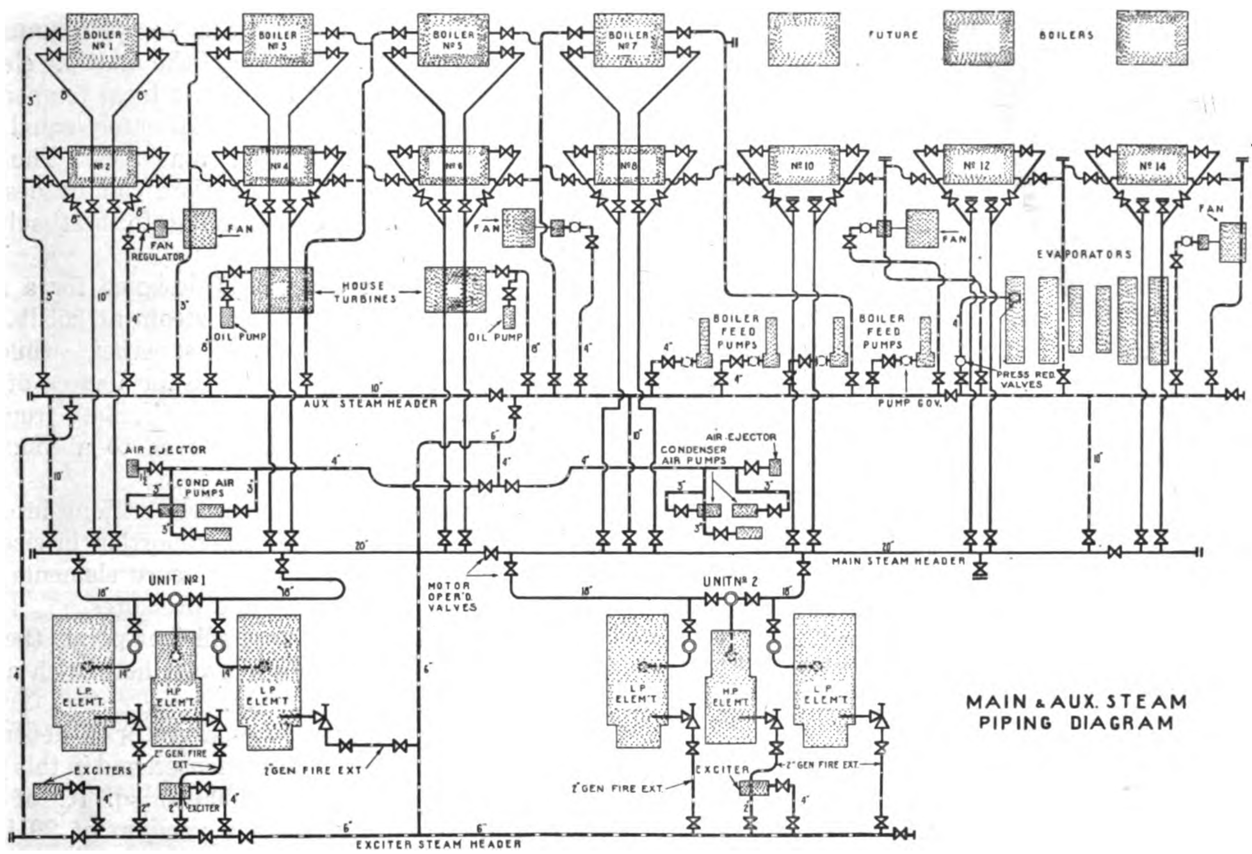


Diagram of Steam Piping

The high-pressure steam pipe which normally supplies only the high-pressure element branches to give an emergency supply to each low-pressure element. Each generator is piped to receive steam from the exciter steam header for use in extinguishing fire in the generator windings. This diagram covers the present unit and a future second unit.

Economy

An important factor in insuring the economical generation of power in this particular plant is its location near a coal mine. A mine mouth location, however, is not adapted to efficient generation unless combined with an ample supply of condensing water. The Colfax plant has therefore been located a short distance from the mine on the Allegheny River which gives a water supply of unusual magnitude for a mining region.

Great care has been taken that the coal should move forward in a simple manner from the mine to the furnaces with a minimum number of handlings and that it should be handled by gravity wherever possible.

A private railroad gives a cheap one-mile haul from the mine to the plant. At the plant the cars arrive

tinuous sample of the coal as it goes to the belts which distribute it to the bunker.

The quantity of coal used is determined by passing it through weighing larries with recording registers on its way from the bunker to the stokers.

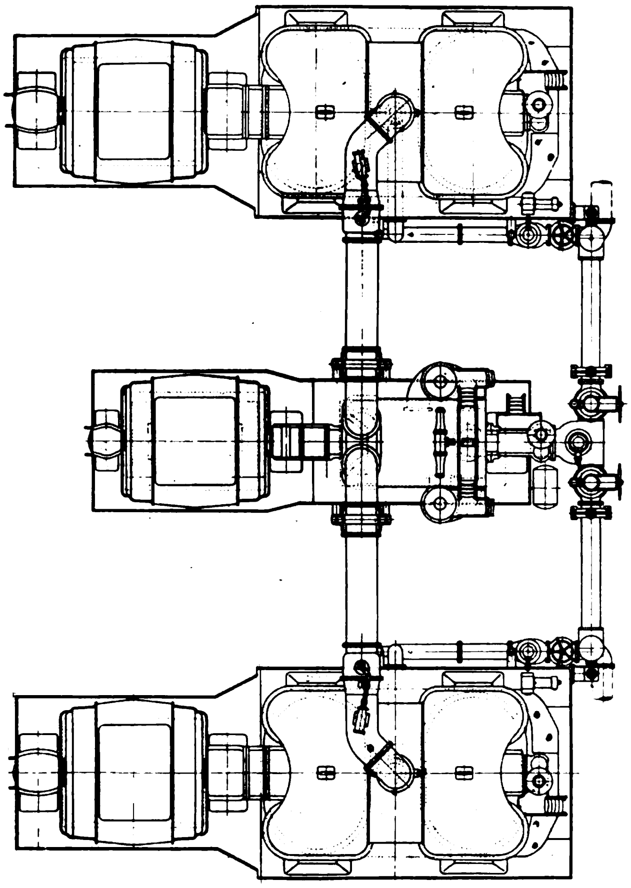
The ashes pass from the furnaces through clinker grinders to large hoppers for temporary storage. Air-operated ash gates discharge the ashes by gravity into standard railway cars in which they are removed without further handling.

From the furnace to the turbine every detail has been carefully considered so that the heat of the coal may be converted to electrical energy with the highest thermal efficiency.

The stokers are extra long and will burn coal at such a rate that the boilers will develop 300 per cent of rating

for peaks. However, so long as the load factor on the station is high a lower annual cost will be obtained by operating the boilers at from 200 per cent to 225 per cent of rating.

The boilers are set exceptionally high so that a furnace volume of approximately 3.45 cu. ft. per rated horse power is obtained. This liberal volume permits of the complete combustion of the coal even at high rates of evaporation in the boilers.



PLAN OF 60,000-KW. UNIT

The plan shows the three elements of one generator. Each element is of 20,000-kw. capacity. The speed of the central element is 1800 rev. per min. and the frequency 60 cycles; the speed of each outside element is 1200 rev. per min. and the frequency 60 cycles. The outer elements are spaced 30 feet on centers from the central element to give ample space around each element for convenient operation and also around the condensers in the basement below.

The boilers are 18 tubes high, which was the greatest height developed at the date of purchase. This gives the maximum amount of heating surface per foot of furnace width which is favorable for abstracting the greatest proportion of the heat from the gases on their way through.

The usual losses caused by air leaking through the brick boiler settings are much reduced in this plant by using steel casings.

A total steam temperature of about 600 deg. fahr. was chosen as giving the highest thermal efficiency consistent with thorough reliability. It was further decided that approximately 200 deg. fahr. of this steam temperature could best be used in the form of superheat. A gage pressure of 275 lb. per sq. in. was chosen in conformity with these considerations. To provide this superheat the superheating surface is 6700 sq. ft. as compared to 20,876 sq. ft. of heating surface in each boiler.

The instruments which are provided to permit of economical boiler operation include feed water regulators, water flow meters, draft gages, pyrometers and CO_2 recorders.

Excellent efficiency of the turbo-generators themselves is an essential element in insuring unusually high plant efficiency. The use of the multiple element type of machine has permitted the total temperature drop to be divided into two approximately equal steps which are utilized in separate machines. The high and low-pressure elements therefore can be designed with different speeds and blading to best suit the steam conditions.

The high-pressure element is designed for a speed of 1800 rev. per min. for taking steam at 265 lb. gage pressure and 175 deg. fahr. of superheat while the low-pressure elements are designed for a speed of 1200 rev. per min. for expanding the steam from an intermediate pressure of 55 lb. gage to a condenser pressure of one in. of mercury.

The division of the low-pressure machine into two elements removes an undue disproportion in size and speed between high- and low-pressure elements with this division of temperature and pressures.

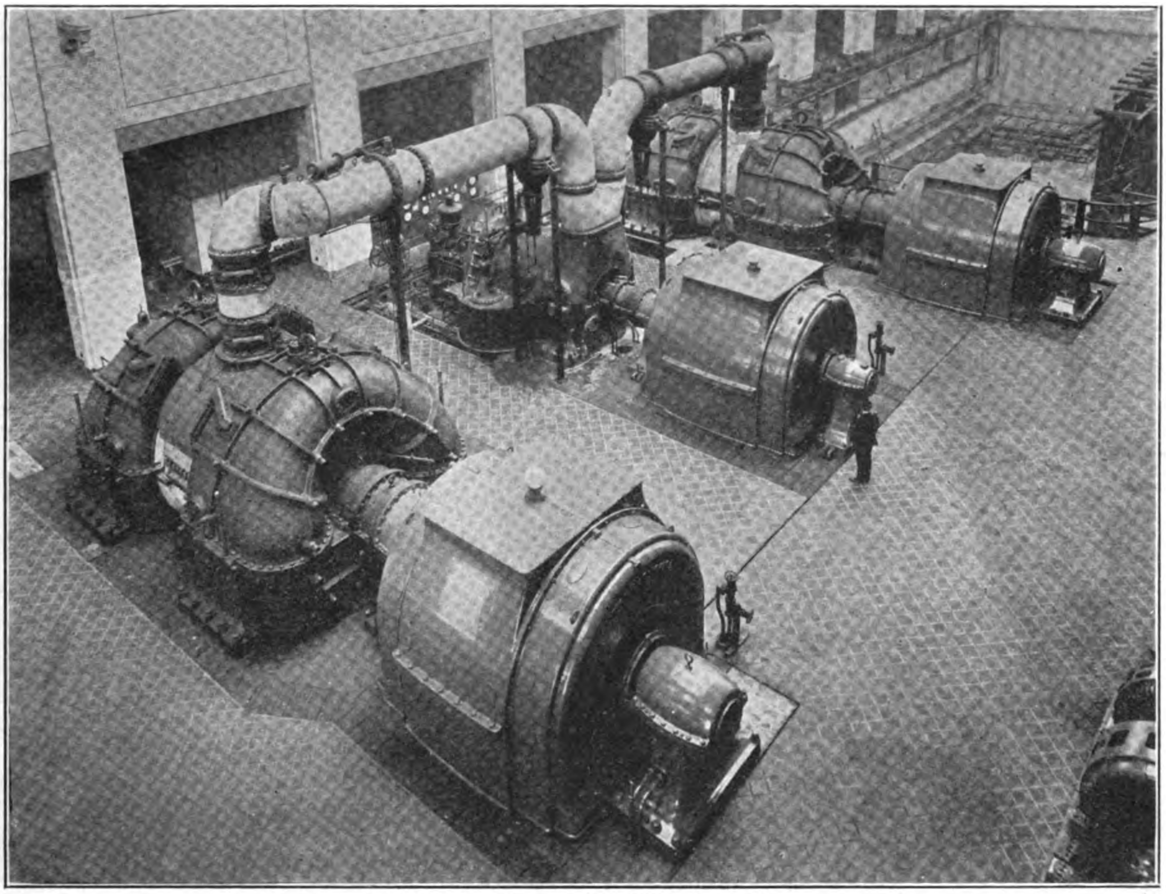
When operating at its most efficient point, the unit is guaranteed to generate a kilowatt hour with a consumption of steam of 10.58 lb.

The efficiency of the turbo-generator is dependent in a large measure on the condenser, and in this plant each unit is provided with 100,000 sq. ft. of condenser surface which insures a vacuum of 29 in. at full load.

While a plant should have a high thermodynamic efficiency if each of the major elements, furnace, boilers, turbines and condensers is highly efficient, there is an opportunity for material losses to occur in the numerous auxiliaries, which, with the best of design, may consume 12 per cent as much steam as the main turbines. In this plant great care has been taken in the design of each auxiliary system to stop all preventable losses.

The feed-water system may be taken for example as the most important of the auxiliary systems.

Under normal full-load conditions approximately 87 per cent of the water evaporated in the boilers is used in the main turbines, is condensed in their condensers and, then reused for boiler feed water. Another 10 per cent is used in operating auxiliaries and may also be condensed and used for boiler feed water. The remaining 3 per cent is accounted for in steam used in soot blowers, boiler blow-downs, drips, drains, vents and so forth where the water cannot be recovered.

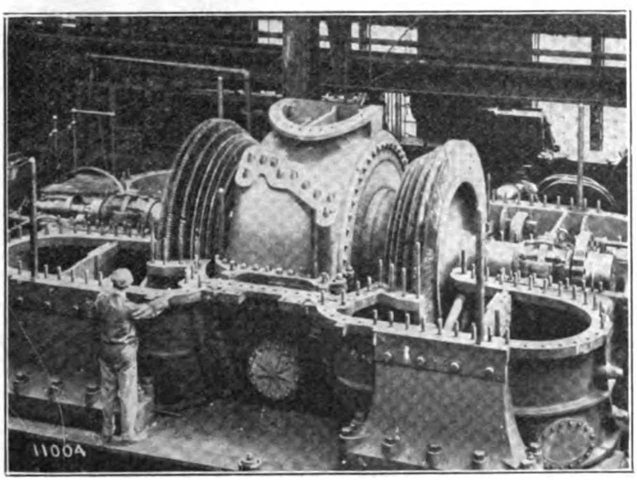


GENERAL VIEW OF 60,000-KW. UNIT

The central or high-pressure element receives steam from the boilers at 265-lb. pressure and exhausts it into the branched overhead pipe through which it passes at about 55 lb. to the two outside low-pressure elements. A butterfly valve in each branch of this pipe permits of this steam passage being closed.

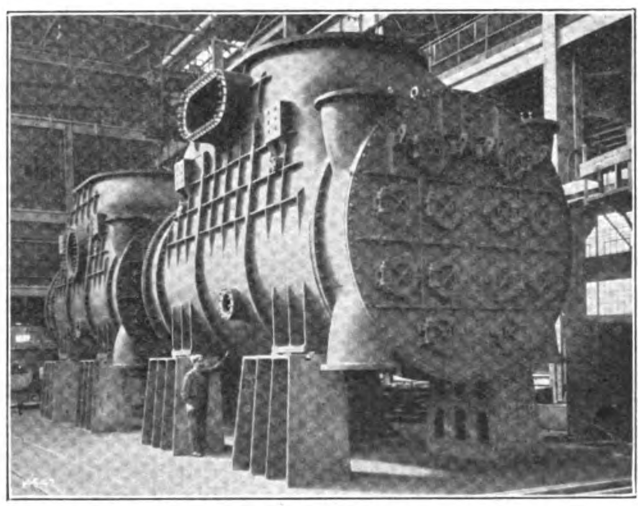
This loss of water is made up by evaporating river or well water to purify it before allowing it to enter the boilers.

The condensate from the main turbines which is the principal source of feed water is removed from the condensers by the hot well pumps at a temperature



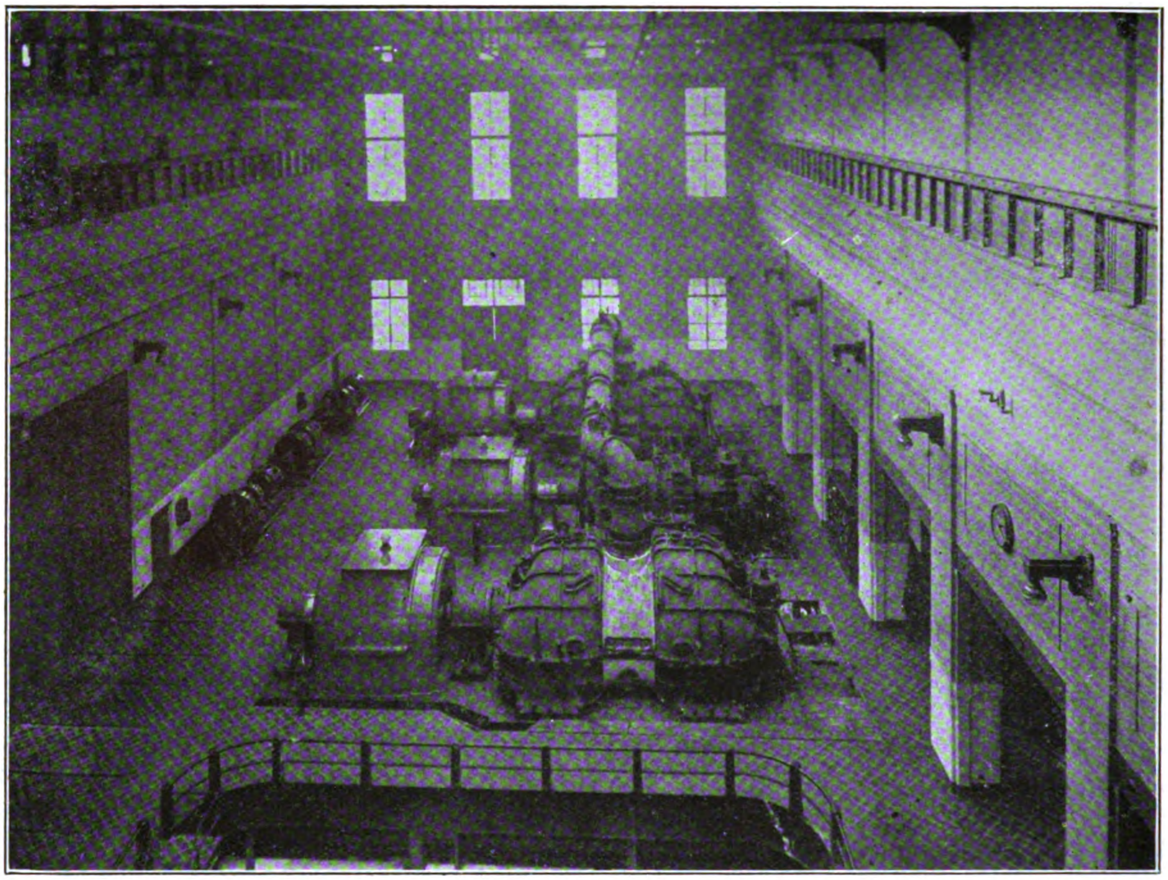
A LOW-PRESSURE ELEMENT

This 20,000-kw. 1200 rev. per min. turbine is of the semi-double flow construction. The steam entering through the opening shown at the top first passes through a section of single flow blading concealed beneath the central casing which is shown in place. The steam then divides and flows toward each end through the double flow blading which is exposed in the view by the removal of the outer casing. At each end the exhaust steam is discharged from the turbine through a separate opening below the floor. These two openings connect with separate condenser shells.



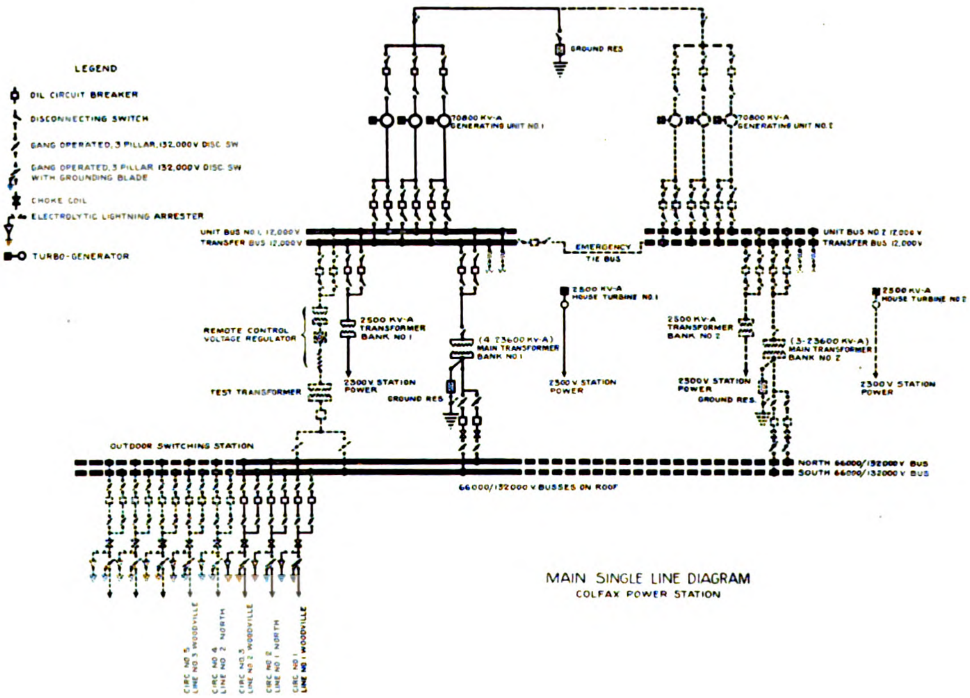
CONDENSER

Each unit has 100,000 sq. ft. of condenser surface divided between four shells. This view taken in the shop shows two shells, that is, one-half of the condenser for one unit. Exhaust steam enters the top of each shell through an elliptical opening 14 feet long and 9 feet wide. The smaller elliptical side outlet is for an equalizing pipe between the two shells of the same element. The divided water box construction which permits of separate cleaning of the halves of each shell is indicated by the duplicate flange on each side for circulating piping. The shell is shown standing on feet which are provided for convenience in erection. When in service it is suspended from a steel framework by straps which attach to the pads just below the equalizing opening.



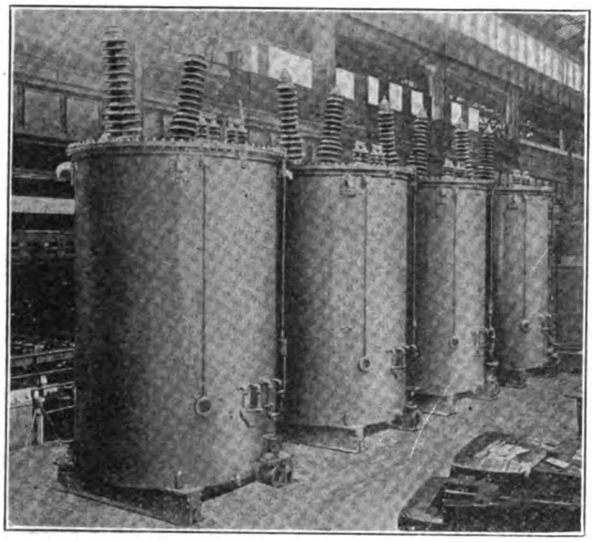
General View of Turbine Room

The units are spaced 125 feet on centers with a pit between for dismantling generators and transformers. The auxiliary bay which opens into the turbine room contains the feed pumps, draft fans and house turbines, thus bringing all steam driven auxiliaries to the turbine room floor and under the care of the turbine room operators.



Main Electrical Connections

The main circuit consists simply of a lead from each element to an isolated 12,000-volt bus which unites the three currents into one, a lead from this bus to a transformer bank which steps the voltage up to 66,000 volts, a lead from the transformer bank to a high-tension bus which carries the current from the power house to a switching station where it divides among three outgoing feeders. To facilitate maintenance and repairs both the low-tension and the high-tension busses are in duplicate with oil selector switches throughout.

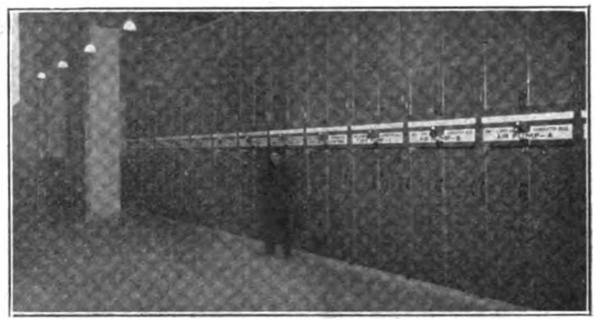


THE FOUR 23,600-KV-A. TRANSFORMERS

These are the largest single-phase transformers that have ever been constructed. Each is approximately 10 feet in diameter and 22 feet high over the terminals. Three of these units form one transformer bank and the fourth is a spare. The low-tension windings are connected delta for 12,000 volts and the high-tension windings are connected star for either 66,000 or 132,000 volts.

of 75 deg. fahr. It is desirable to raise the temperature of this water to about 200 deg. fahr. and to add to it the water used by the auxiliaries and the make-up water from the evaporator before pumping it into the boilers. It is furthermore desirable that all heat transferred in the process should be most efficiently utilized.

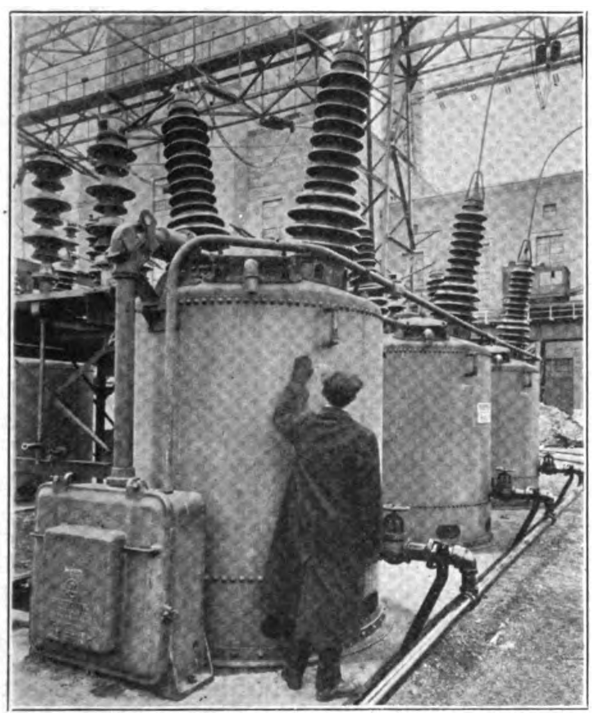
In this plant the process is therefore divided into several steps.



2300-VOLT BUS STRUCTURE

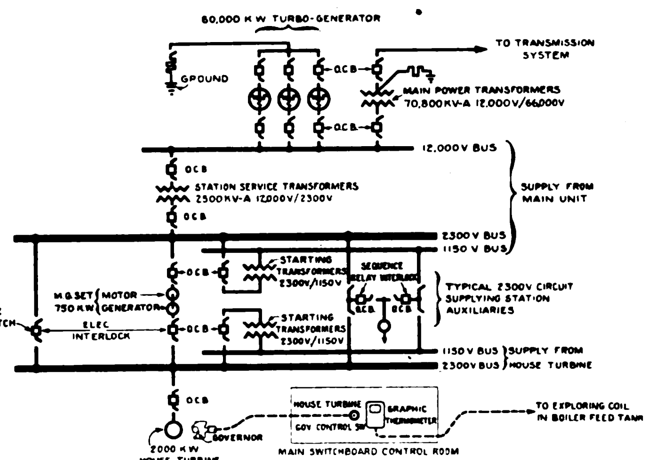
The 2300-volt circuits are used exclusively for supplying station auxiliaries. The 2300 system is supplied from duplicate sources, a separate 2000-kw. house turbine and a 2500-kw. bank of station transformers. As absolute dependence has been placed on electric drive for a majority of the essential auxiliaries the 2300-volt busses have been carefully safeguarded in cell work.

1. The auxiliary live steam is used to produce as much mechanical power as possible before its heat is used for other purposes. The auxiliaries which are steam-driven are the feed pumps, the forced draft fans and the house turbo-generator. The amount of exhaust steam from the feed pumps and draft fans is always less than the minimum necessary and the additional steam from the house turbine may be controlled at will by transferring load electrically between the generators of the house turbine and the main turbine.



A 132,000-VOLT, 400-AMPERE CIRCUIT BREAKER

The three tanks shown form a single three-pole oil circuit breaker. There are two of these breakers in the power station to control the high-tension circuit from the transformer bank and six in the outdoor switching station to control the three outgoing lines. Each switch is electrically operated by mechanism enclosed in the iron box shown at the end of the row of tanks. The electrical operation is by remote control from the switchboard.



CIRCUIT DIAGRAM AUXILIARIES & HEAT BALANCE CONTROL

DIAGRAM OF AUXILIARY CIRCUITS

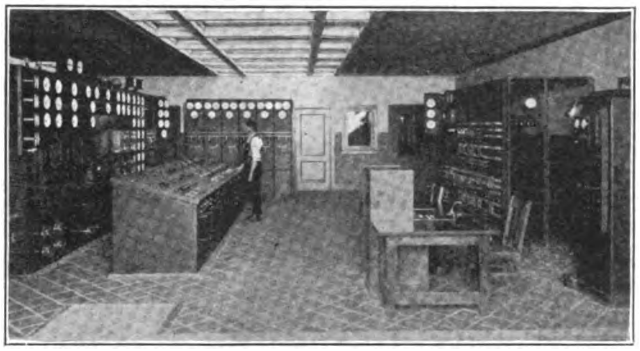
The essential auxiliary connections showing method of heat balance control from switchboard room.

2. Part of the exhaust steam from the auxiliaries is first used in the evaporator for evaporating make-up water.

3. The heat used in the evaporator is again recovered

and adds some 20 deg. to 30 deg. to the temperature of the main condensate which passes as circulating water through the condenser of the evaporator to condense the make-up water.

4. The steam from the auxiliaries, which is not needed in the evaporator, is condensed in a barometric condenser, which uses as condensing water the condensate from the main condensers that has already been raised in temperature 20 deg. or 30 deg. as above mentioned.



CONTROL ROOM

This shows the room 48 ft. long by 30 ft. wide from which the plant is controlled.

This combination is designed to maintain the feed water at a normal temperature of about 200 deg. fahr. without waste of either water or heat.

The electrical method of transferring the load between the house turbine and main turbine is particularly interesting. Practically all the station auxiliaries are electrically operated by induction motors which are normally supplied from the house turbine circuit. The house turbine circuit has, however, a second source of supply from a generator driven by an induction motor receiving its supply from the main generators. When the house turbine is run at the same frequency as the main generators the motor-generator will furnish no power and the house turbine will carry all of the electrical station auxiliaries alone. The speed of the house turbine is adjustable by the usual governor control, and as its speed is reduced the motor-generator will pick up load on the house circuit. The whole load or any part of it may be transferred from the house generator to the main generator.

The electrical losses inside of generating stations are so small that large savings are not possible, but in this plant there has been some improvement in transformer efficiencies. These transformers which are larger than any other single-phase units yet constructed have the high full-load efficiency of 99 per cent.

Records are not yet available to show the normal performance of the plant in actual service, but calculated figures indicate that at a load of 50,000 kilowatts, its coal consumption should be about 1.39 lb. per kw-hr.

RELIABILITY

Reliability without sacrifice of economy has been the next major consideration in the plant design.

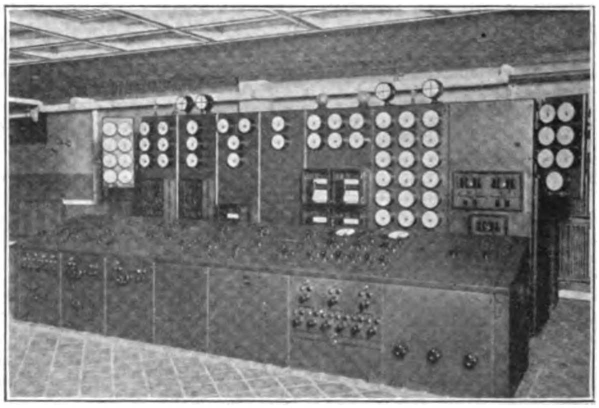
The coal supply is the first point requiring safe-guarding. The natural coal supply of the Colfax plant is direct from the Harwick mine. Two alternative methods of supply are however provided, either by barge on the river or by car over the Pennsylvania Railroad. Finally a coal storage of 150,000 tons within a few feet of the power station makes interruption of fuel supply a remote contingency.

Inside the power house the coal hoppers, coal crushers, coal elevators and conveyors are all in duplicate and each half has a capacity of 200 tons per hour. Furthermore, the coal bunker provides a storage of 240 tons immediately over each boiler.

The number and capacity of the boilers is such that it is always possible to take a boiler out of service when it is desirable for cleaning or proper maintenance.

The furnaces are designed to permit high furnace temperature with a minimum of brickwork upkeep.

In the high-pressure steam piping, special care has been used to insure reliability. Thus in the flanged joints double threaded bolts with two nuts of special high-grade, oil-treated steel are used. This avoids upsetting the material to form a head and results in a more reliable bolt.



MAIN BENCH BOARD

This is the board from which all the main circuits are controlled. On top of the desk apron there are mimic busbars representing the actual circuits in diagrammatic form. Circuits of different potential are distinguished by the use of different finishes for these busbars.

The division of the main unit into three mechanically distinct elements minimizes the loss of capacity from an accident to the machine, as any two of the elements may be operated with the other out of service or any one may be operated with the other two out.

Normally, all the steam supplied to the unit is under the control of the governor on the high-pressure element, but each low-pressure element is also equipped with a governor.

The closing of a butterfly valve in one branch of the steam pipe between the high and low-pressure cylinders

cuts off the low-pressure steam supply to that low-pressure element. Then the opening of a direct steam connection to the boilers permits of that low-pressure element being operated as an independent condensing turbine on its own governor. Either or both of the low-pressure elements may be so operated.

With the butterfly valves closed in both branches of the pipe between the high and low-pressure cylinders and with the atmospheric relief valve open, the high-pressure element may be operated as an independent non-condensing turbine.

The opening and closing of the proper valves for shifting to separate operation in case of an emergency is automatically controlled by the governors.

Overspeeding of a low-pressure element closes the butterfly valve and cuts off its low-pressure steam supply while a drop in speed admits live steam from the boilers.

Overspeeding of the unit cuts off all steam from the unit and closes both butterfly valves, but a subsequent slowing down will admit live steam to the low-pressure elements.

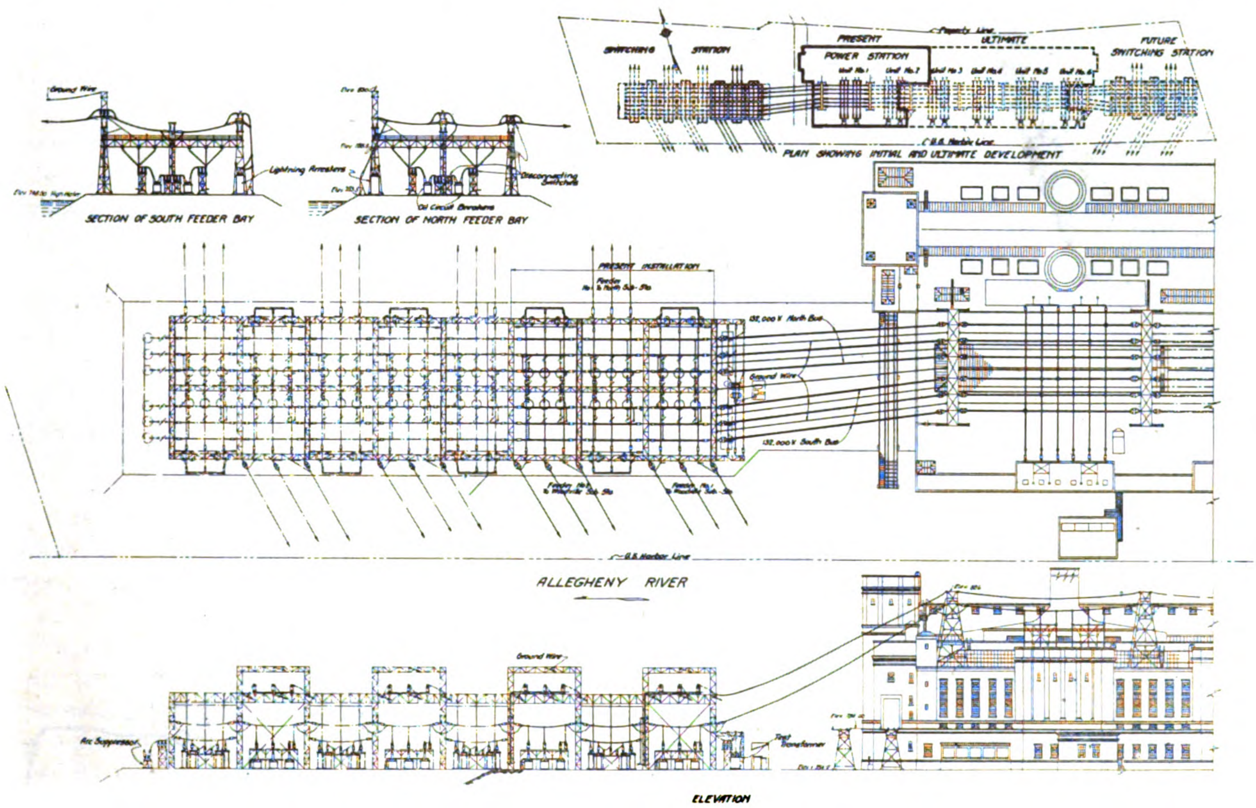
Each of the low-pressure elements is of the semi-double flow type with two exhausts from each cylinder. This has naturally resulted in dividing the condenser surface between four shells. Each shell is so divided that one-half of it may be isolated for cleaning, permitting one-eighth of the total surface to be cleaned at a time without interruption to service.

The excitation system is especially well protected against interruptions. The exciters are in duplicate, one being a spare machine. The exciters are normally motor-driven, but each is also connected to a steam turbine. When the exciter is being driven by the motor, a small amount of live steam is admitted to the turbine casing and if the motor permits the speed to fall, the turbine automatically takes the load from the motor and maintains the excitation.

The electrical devices provided for protecting the generator include a differential relay operated by the difference between the line and neutral current which will automatically perform all the functions necessary for isolating that generating element in case of an internal short circuit; a resistor of seven ohms between the generator neutrals and ground which limits the current to ground on the 12,000-volt system to 1000 amperes; and six resistance coils and six thermocouples for temperature measurement.

Great care has been used in insulating the connections from the generators to the busses. These consist of cables insulated for 13,000 volts, mounted on porcelain insulators as an additional precaution.

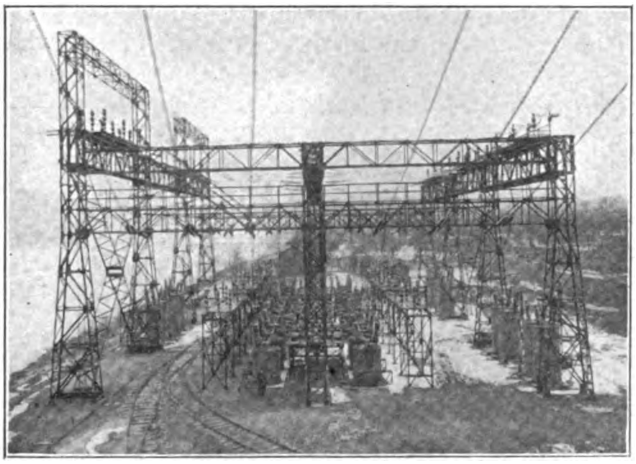
Four single-phase step-up transformers are installed, of which one is a spare unit. The spare transformer has all piping connections in place and is provided with disconnecting switches on the low-voltage side and removable pipe links on the high-voltage side, by means of which it can be connected



OUTDOOR SWITCHING STATION

The high-tension busses extend in a continuous line the length of the turbine room roof, thence across an intervening space to the switching station and then the length of the switching station. The switching station is divided at right angles to the busses into bays, each bay being used to control a separate line.

in place of any of the others in a few minutes. Each transformer has two hot-spot temperature indicators, one at the switchboard and one at the transformer, designed to show the highest temperature existing at the hottest spot in the transformer coils. The transformers are protected by differential relays in case of internal short circuits and by heavily set overload relays in case of a short circuit on the high-tension busses. The neutral of the high-voltage windings of



OUTDOOR SWITCHING STATION

The station consists of an iron framework supporting the insulators, horn gaps, conductors and disconnecting switches which are required. Oil circuit breakers and lightning arresters which stand on the ground.

the transformer bank is connected to ground through a resistance, which will limit the current in case of a ground on the high-tension circuit.

All electrical auxiliaries have duplicate sources of supply and may be operated from either the main generators or the house turbine.

The motor-generator which normally interconnects the main and the house turbine has reverse power relays which will disconnect it in case the frequency of the main turbine falls to a point where it would materially interfere with the operation of the house turbine or station auxiliaries.

In order that disconnecting switches may be opened and closed only when the corresponding oil switch is open, each set of switches is provided with a protective device, including as the indicating element, three lamps. A red light indicates a closed circuit breaker, a green light that the breaker is open and a white light that the control wires to the breaker are open.

Electric control is used for so many operations that a dependable supply is essential. Duplicate batteries, charging sets and busses are provided. Each circuit is equipped with a double throw switch for connecting to either bus.

A complete emergency lighting system provides sufficient light at every important point to permit of the operation of the station without hazard. When the normal alternating-current supply of the emergency lighting circuits is interrupted, connection is automatically made to a storage battery.

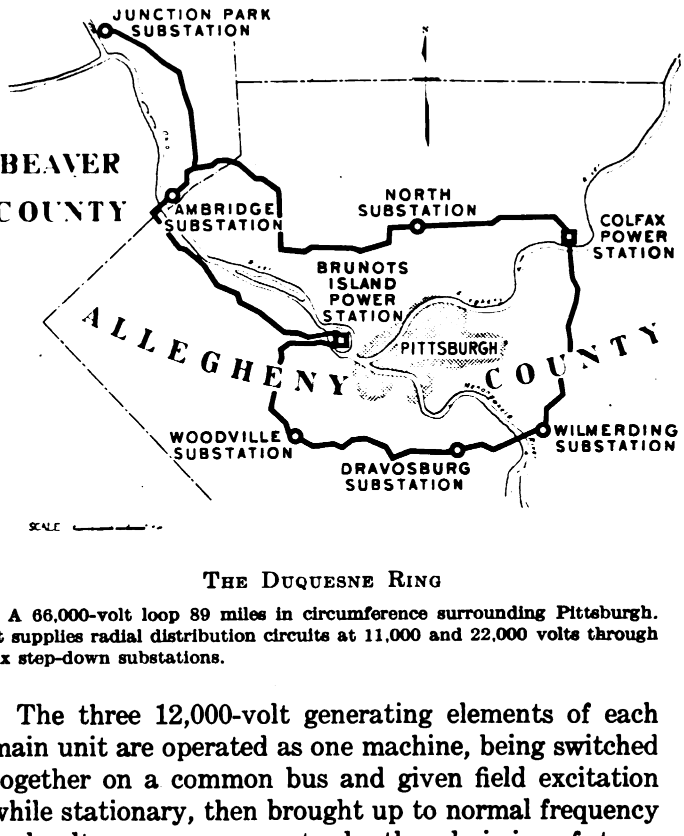
The various precautions to insure reliability above described may be summarized as including, first, careful design and a high factor of safety to prevent accidents, second, a complete duplication of all important but inexpensive elements so that complete service may be maintained in spite of any failure, and third, a subdivision of the large and expensive elements so that a failure merely causes a diminution of capacity without an interruption to service.

SIMPLICITY

Simplicity of design has been favored by the large size of the units, but great care has been necessary to attain reliability while preserving the simplicity.

The low steam consumption of the turbine and the large capacity of the individual boilers have simplified the boiler room by permitting a single firing aisle.

Each turbo-generator is regarded as a single unit taking steam through a single governor and delivering high-tension current through a single transformer bank. The division of the unit into three mechanical elements and the resulting division of the generated current into three low-tension circuits are regarded as internal structural peculiarities which can be taken advantage of in case of an emergency but which should not be made an excuse for complicating the design.



THE DUQUESNE RING

A 66,000-volt loop 89 miles in circumference surrounding Pittsburgh. It supplies radial distribution circuits at 11,000 and 22,000 volts through six step-down substations.

The three 12,000-volt generating elements of each main unit are operated as one machine, being switched together on a common bus and given field excitation while stationary, then brought up to normal frequency and voltage as one generator by the admission of steam to the high-pressure turbine and synchronized with the 66,000-volt system through the low-tension circuit breakers of the 70,000-kv-a. transformer bank.

When other units are added each is to have its own isolated 12,000-volt bus. Each generating unit may be considered as a single 66,000-volt machine. The station bus on which the machines operate in multiple is the high-tension bus from which the transmission circuits are supplied. This simple plan has been developed by taking advantage of the location of Colfax at a point where the local loads are not heavy and recognizing that there would be an undue expense and complication if a common low-tension bus were established in order to supply a small local load.

The use of a single transformer bank for each three-element unit simplifies the transformer house while the use of single-phase transformers provides a subdivision of the capacity which gives added reliability without complication or expense.

Another simplification in the power house is obtained by separating the distribution of power from its generation. With this plan the only switches in the power house are those of the generators and auxiliaries. The only high-tension switches which must be provided for in the power house design are two selector switches for each generator. After passing through these switches the generator circuits go out doors to the duplicate station busses which are suspended above the roof. The current thus leaves the power station proper at one end over two busses.

The distribution of power from a separate point permits the use of a simpler design and less expensive construction for this purpose than would be necessary in the power station building.

These simplifications in design have been important factors in keeping down the cost of the station. In spite of the fact that the station was constructed just at the time when the prices of material and labor were at their maximum the cost of that part of the plant which should be allocated to the first unit was about $105 per kilowatt.

APPENDIX

CAPACITY AND RATING OF APPARATUS

Coal Handling Apparatus. Duplicate concrete receiving track hoppers, each 150 tons capacity.

Duplicate crushers, each 200 tons per hour capacity.

Duplicate bucket elevators with overlapping, pivoted buckets, each 200 tons per hour capacity.

Duplicate 30-in. belt conveyers, each 200 tons per hour capacity.

Reinforced concrete bunker, capacity 10 tons, per lin. ft., or 240 tons per boiler.

Duplicate weighing larries, each 20 tons capacity.

Stokers. 17-retort, extra long underfeed with double roll clinker grinders.

Ash Handling Apparatus. Ash hoppers of reinforced concrete, brick-lined, 1900-cu. ft. capacity per boiler, fitted with air-operated ash gates, discharging direct into standard gage railroad cars.

Boilers. Seven Babcock & Wilcox steel-cased cross-drum boilers. Each contains 20,876 sq. ft. of heating surface, is 51 tubes wide and 18 tubes high. Tubes 20 ft. long; diameter of cross-drum 60 in.; steam pressure 275 lb.; furnace volume 3.45 cu. ft. per rated h. p.

Superheaters: Foster type, located above tubes between first and second pass. Each contains 6700 sq. ft. of heating surface giving from 140 deg. to 200 deg. superheat.

Forced Draft System. Three 250,000-cu. ft. per min. fans driven by 420-h. p. geared steam turbines. Air supply taken from generator discharge and boiler room basement.

Stacks. Two brick lined self-supporting steel stacks, each 21-ft. diameter with top 325 ft. above firing floor. Flues are above roof and covered with magnesia with sheet metal protection.

Main Turbo-Generator. One Westinghouse 60,000-kw. three-cylinder, two-stage parallel flow, compound steam turbine generator unit consisting of one 1800-rev. per min., single-flow high pressure element, and two 1200-rev. per min. semi-double-flow low-pressure elements; each element driving one 23,600-kv-a., 85 per cent power factor, 60-cycle, 12,000-volt, three-phase generator. Generators are star-connected with three neutral connections brought out; seven-ohm external resistance in ground circuit.

Main Unit Auxiliaries. Condensing equipment has 100,000 sq. ft. of surface in 4 two-pass shells of 25,000 sq. ft. each, connected to turbines by means of rubber expansion joints. Each condenser shell contains 5070 one-in. Muntz metal No. 16 gage tubes of 18 ft.-10 in. active length.

Three circulating pumps, each 44,000 gal. per min., motor-driven.

Four condensate pumps, each 1000 gal. per min., two-stage, motor-driven.

Three Leblanc air pumps, each 30 cu. ft. per min., motor-driven.

Two submerged removal pumps, each 900 gal. per min., motor-driven.

Two air washers, each 115,000 cu. ft. per min.

Station Auxiliaries. "House" turbo-generator: One 2000 kw. 2300-volt, three-phase, 60-cycle unit, the turbine operating at boiler pressure and exhausting into barometric condenser.

Heat balance set: One 1100-h. p. 2300-volt, three-phase 60-cycle motor driving 750-kw., three-phase, 60-cycle, 900-rev. per min. 2300-volt synchronous generator. This set connected between the house turbine bus and the auxiliary bus fed from main turbo-generator.

Duplex exciters: Two sets, each consisting of a steam turbine on common shaft with 350-kw. 250-volt, d-c. generator and 530-h. p. 2300-volt motor.

Motor-generator sets for stoker and clinker grinder supply: Two, each consisting of 325-h. p. three-phase, 60-cycle, 2300-volt motor driving 200-kw. 250-volt, d.c. generator.

Battery charging sets: Two, each consisting of 25-h. p. three-phase, 60-cycle, 440-volt motor driving 15-kw. 125-volt, d-c. generator.

Elevator: Combination passenger and freight, automatic, two-ton capacity; to all floors on electrical bay side.

Evaporator, double effect, "dry-tube" type: Capacity 15 tons per hour. The two effects reversible.

Three boiler feed pumps: Each 1500 gal. per min. four-stage centrifugal, turbine-driven.

Main distilled water storage tank: Capacity 200,000 gallons.

Traveling crane: One four-motor, 75-ton main hoist, 25-ton auxiliary hoist.

Transformers. Main Transformers: Four 23,600-kv-a. 11,500/38,100/76,200-volt single-phase, 60-cycle, oil-insulated, water-cooled, low-tension delta, high-tension star. One transformer in reserve as spare.

Station Transformers: Three 833-1/3-kv-a. 11,500/2,300-volt single-phase, 60-cycle, oil-insulated, water-cooled, connected delta-delta.

Duplicate Storage Batteries. For circuit breaker control and emergency lighting. Each 125-volt, 160-ampere-hour.

Main Switchboard. Desk type for controls, vertical panels in rear for instruments on main board of seven sections. All other boards of vertical type. Panels of slate. Mimic busses of all circuits with different finish for each voltage.

Circuit Breakers. Remote control, solenoid-operated, type O-2 and CO-2 on 12,000-volt circuits; type G-2 on high-tension circuits.

Emergency Lighting. Emergency lights throughout plant automatically transferred from normal supply to storage batteries in case of station trouble; restored when trouble is removed.

Telephone, Etc. Duplicate private branch exchange boards. Telephones installed in all parts of building and important points outside of station. Loud speaker on main instrument board permits operator to talk without head set.

Master clock in control room with auxiliary clocks in various parts of building.

Load indicator in center of boiler room firing aisle with double-faced illuminated dial electric clock and steam gage.

Signal System. Induction regulator type sending and reeiving indicators and transmitters between control room and gage boards.

The Frequency Problem in the Steel Industry

BY B. G. LAMME

Chief Engineer, Westinghouse Elec. & Mfg. Co.

The standard frequency of 25 cycles for steel mill plants was adopted many years ago, when the conditions were such that this frequency more nearly met the steel mill requirements than was possible with 60 cycles. With the coming of large central power stations, for the general supply of electric service of all kinds, the frequency of 60 cycles has come into more general use. In consequence, in considering the purchase of power from the large supply companies, the steel mills are now confronted with the problem of utilizing 60 cycles to best advantage in plants which were initially designed for 25 cycles.

Various possibilities for utilization of 60 cycles in such plants are given, and the advantages and disadvantages of each are discussed briefly.

The intent of the paper is to bring forward certain points for free discussion, rather than to attempt to solve the problem, it being recognized that the whole matter is too complex and contains too many varied elements to allow any entirely satisfactory general solution.

SOME fifteen years ago, recognizing the advisability for standardization of certain requirements in connection with their work, the steel mill engineers took up the question of choice of frequency. At the time all the electric power used by the steel mills was produced in their own plants, and, in many cases, such plants were of relatively large capacity compared with central stations. Apparently there was no question then regarding advisability of the generation of their own power, as this was the only way in which they could obtain electric power.

At the time there were only two frequencies in general use in this country, namely, 25 and 60 cycles. The steel mill engineers, therefore, confined themselves to a comparison of these two frequencies, and their fitness for steel mill work in general. Various applications of electricity to steel mills then in use, and in contemplation, were gone into quite fully. The manufacturers of electric and other machinery were consulted quite fully regarding the possibilities of the various types of apparatus and equipment. At that time there were three conditions of service which required special consideration, namely, (1) the operation of large very low-speed induction motors: (2) the transformation from alternating to direct current; and (3) the parallel operation of low-speed gas-engine-driven generating sets. These three conditions will be gone into more fully.

At the time that this study was made, much of the heavier service of the steel mills was contemplated at relatively low speeds with direct-connected motors, or with as little gearing as possible, on the basis that large, high-speed, high-power gears would not be satisfactory. As motors up to 6000-h. p. nominal rating, with speeds of 75 to 90 rev. per min. were considered necessary in certain applications, it appeared, from all points of view, that for such work 25 cycles was far better than 60, both from the standpoint of the general performance and the first cost.

In transformation to direct current, both synchronous converters (or "rotaries" as they are often called) and motor-generators were recognized as possible methods. With synchronous converters, 25 cycles offered by far the better proposition, compared with the 60-cycle synchronous converters of that time; whereas, with motor-generators, there was not much difference. With induction-motor drive, for motor-generator sets, naturally the lower frequency appeared to offer advantages, while with synchronous motor drive, the 60-cycle possibly was better. It must be borne in mind that in those days the high-speed d-c. commutating-pole generator, as we now know it, was not yet developed, and, therefore, with the then relatively low speeds of motor-generator sets, 25-cycle synchronous driving motors were fairly comparable with 60 cycles, while with induction-motor drive the advantage naturally was with 25 cycles. The coming of the commutating-pole d-c. machines, with consequent very much higher speeds, has greatly changed the situation, as will be referred to later.

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The third condition mentioned, namely, parallel operation, is one which concerned, principally, gas-engine drives. It was the belief that by using furnace gases with suitable large, low-speed, gas engines, the most economical generation of power would be obtained. The Gary plant is an illustration of this early tendency. It was well-known, at the time, that, with 25 cycles, parallel operation of alternators, with gas-engine drive, was a much easier proposition than with 60 cycles, and even with 25 cycles there were some doubts regarding successful paralleling.

This Gary plant should be referred to further as an illustration of certain extreme conditions undertaken in some of the earlier pioneering in electrification of steel mills. Everything was more or less new and special in this electrification and this was frequently cited as an illustration of an entirely electric-driven steel mill. In this early plant, there were many conditions of motor drive which, even with very low-speed motors, still required huge gears for still further reduction in speed. Some of the ultimate speeds, at the load, corresponded to six to ten revolutions with direct motor drive, obviously representing impossible conditions as far as direct motor applications were concerned. Even with gearing, the conditions of motor drive were such that 60 cycles would have represented impracticable conditions, so that 25 cycles was a practical necessity in this plant as designed. This Gary plant had a very decided influence in fixing 25 cycles as a standard for steel mill work.

Taking all the various conditions into consideration, the steel mill engineers decided definitely upon 25 cycles as their future standard for generating plants. A standard voltage of 6600 was also decided upon, although this was not considered as of first importance, but practically amounted to setting an upper limit. It was felt that there would be considerable use for lower voltages, such as 2200, and in fact, experience has shown that, in the smaller plants, 2200 volts is used more than 6600.

This choice of 25 cycles at that time, was undoubtedly the correct one, with the knowledge and experience available, and it may be stated emphatically that no real mistake was made in this choice of frequency. It may be said, moreover, that if 60 cycles had been chosen, instead of 25 cycles, at the time, it is probable that steel mill electrification would have been greatly handicapped in many ways and would not have reached nearly the stage of development that has been attained today.

However, new conditions have arisen in recent years which have changed the complexion of the problem to a certain extent. Fifteen years ago it was believed quite generally, that 25 cycles would be the future power frequency of the country on account of its general advantages in generation, transmission, utilization and transformation to direct current. If this was true of the general problem, it applied still more positively to the steel mill situation. The whole trend for large power service seemed to be toward 25 cycles; but, for lighting purposes, 60 cycles was favored as being by far the more desirable frequency.

From the central station standpoint, however, the situation gradually changed. One of the big handicaps of the 60-cycle system was in the greater difficulties in transformation to direct current. The 60-cycle synchronous converter, while operative in a fairly satisfactory manner in some applications, was considered quite unsatisfactory in others. This, therefore, meant that motor-generators were required, to a considerable extent, in connection with 60-cycle generating plants, while with 25 cycles, synchronous converters were used almost exclusively. Thus the large generating plants for operating d-c. railway service and those for operating the three-wire d-c. Edison systems went almost exclusively to 25 cycles, mainly on account of the advantages of synchronous converters over motor-generators. However, improvements in the 60-cycle synchronous converter, making it a better operating machine, appeared about fifteen years ago, but nevertheless the machine, being of the non-commutating pole type, was of relatively low speed, with many poles, and was unduly complicated and expensive and inefficient. The coming of the commutating poles in d-c. generators was naturally followed, although several years later, by the use of similar poles in synchronous converters beginning about 1911. At first the use of commutating poles on synchronous converters was considered as unnecessary, and simply in the nature of a refinement, due to their relatively low speeds, and there was some truth in this. However, the use of commutating poles on synchronous converters immediately opened the way to very much higher speeds, so that within a year or two after their real introduction, the speeds of both 25 and 60-cycle synchronous converters began to climb at a rapid rate. Here, however, the 60-cycle converter had the advantage, for soon the 25-cycle machines reached their limiting minimum number of poles; whereas the 60-cycle machine could go to materially higher speeds before reaching such limits. Consequently, in this race toward higher speeds, the 60-cycle synchronous converter, in the smaller capacities, especially, soon outran the 25-cycle, while in the larger machines, it made such a good showing relatively, that it put the 60-cycle generating system nearly on a par with the 25-cycle from the standpoint of transforming to direct current. Here was a big step in favor of 60 cycles.

In the development of induction motors, the tendency also was toward higher speeds. In the small sizes of 25-cycle induction motors, there is not much choice in speeds on account of the few combinations of poles which are possible. Here 60 cycles presented material advantages in offering very much higher

speed machines for general power purposes, with the resultant lower first costs. 1200 and 1800 revolutions, corresponding to six and four poles, respectively, became common practise on 60 cycles; whereas 750 rev. per min. was practically the nearest corresponding 25-cycle machine. Of course, two-pole, 1500 rev. per min., 25-cycle machines are possible, but it happens that, for constructive reasons, the two-pole machine does not show any material advantage in cost or otherwise over the four-pole machine.

From a third standpoint, namely, power generating units, 60 cycles also soon presented advantages. In the earlier days of the turbo-generator, the 25-cycle, two-pole, 1500-rev. per min. unit was favored over the 60-cycle, six-pole, 1200-rev. per min. of corresponding capacity. However, in the race toward higher speeds, which has occurred in the turbo-generator practise as well as in other lines of electrical design, the 1200-rev. per min., six-pole machine was dropped in favor of the 1800-rev. per min., four-pole machine, thus putting the advantage somewhat in favor of 60 cycles. Moreover, up to 5000 kw., a 3600-rev. per min., two-pole machine at 60 cycles became possible; whereas the best that the 25-cycle frequency could offer was 1500 rev. per min.

In transformer development, in the early days, it looked at first as if 25 cycles had all the advantage, due to the fact that the iron losses were relatively much lower and, therefore, the iron in the magnetic circuit could be worked at very much higher flux densities. However, with improvements in the quality of transformer steel, such as the introduction of silicon steel, it was found that with either 25 or 60 cycles the flux densities could be worked up to such a point that saturation of the magnetic circuit, and in consequence the magnetizing current itself, became one of the limiting conditions. Thus 25 cycles represented simply lower losses in the transformer iron, which were more than counterbalanced by the increased quantity of iron required, so that the advantage began to be on the side of the 60 cycles; and in later development the 60-cycle transformer, as a rule, has proved to be materially smaller, lighter and cheaper than its 25-cycle competitor.

Thus it may be seen from the few indications given above, that there were strong reasons for the trend toward 60 cycles for general power generation and distribution. The transmission advantages at first seemed to be in favor of 25 cycles. However, transmission voltages soon rose from 11,000 to 22,000, 33,000, 44,000, 66,000, 110,000, 132,000, 154,000, and now 220,000 is to be tried out soon, and with these higher voltages the 60-cycle transmission has proved to be sufficiently satisfactory; so that taking generation, transformation, transmission, distribution and the nature of the load into account, the sum total of the advantages has been considerably in favor of 60 cycles.

Another consideration must be taken into account, namely, fifteen to twenty years ago large control stations for general power supply were almost unknown. There were lighting stations and there were railway stations and there were power stations furnishing individual industries, but there were practically no central stations for the general supply of power for all purposes, as have developed during the past few years. With the gradual recognition of the advantages of centralized power plants, the smaller lighting and general power distributing stations began to expand and reach out toward the isolated and special service plants. Gradually as the central stations increased in capacity, they began to make special power rates to the railway companies and to the industrial plants, which were better than these plants could obtain from their own generating plants. Consequently, there was soon a tendency toward shutting down the individual plants, with purchase of power from the central plant. This action has been cumulative, for the more load that was taken over by the central plant, the bigger the central plant became, and the better rates it could make, etc. In this growth the tendency has been very largely, and in recent years almost exclusively, toward 60 cycles as a general purpose frequency.

Naturally, in reaching out for more load, these large central power plants have gone after the steel industry along with other industries, and here is where the steel mill problem of frequency has become prominent. As many of these steel mills, especially the older ones, are already equipped for 25 cycles, the problem has been that of best adapting the 60-cycle frequency where power is to be purchased.

In the former days, the steel mill could compete quite favorably with the central station in the cost of power. However, with the increased growth of the central power stations and their lower rates for power, the steel mills are naturally strongly tempted toward the purchase of power. Even though the steel power plant may be able to generate power as cheaply as it can be purchased, it still is not, in itself, an attractive investment as capital is not, as a rule, invested in the steel industry without the expectation of a reasonable return. As some of the steel mill engineers have said, their business is to produce steel and not manufacture power, and, therefore, naturally they cannot compete in many cases with those whose sole business is the manufacture and sale of power.

One condition which now lends itself toward the use of 60 cycles in steel mill work has been the increased use of gearing, thus allowing higher speed motors. For many kinds of service, gearing is now used where direct connection, a few years ago, was considered as the only method. In consequence, the speeds of the motors used in steel mill work will average much higher than a few years ago.

On the other hand, however, there are certain pre-

judices against large gears for heavy service, based to a large extent upon more or less unfortunate experiences. However, through greater experience and with more suitable types of gears, this prejudice is disappearing to a very great extent. As in everything else, there has been considerable development in the gear situation to meet many of the applications, and while there may be individual cases where gears are not looked upon favorably, yet it must be admitted that the general tendency in recent years has been quite strongly toward higher speed motors with gearing. Regardless of whether or not it represents the best engineering, the trend is toward such gearing, and, as a rule, where a trend persists it must sooner or later become recognized as desirable practise. The law of the survival of the fittest holds in steel mill machinery as well as in everything else.

Of course, it must be borne in mind that operative low-speed motors can be built as well for 60 cycles as for 25 cycles, but with either lower power factor or with high cost. In some cases, lower power factor may not be an important item. To state it plainly, with equal power factors, a low-speed 25-cycle induction motor is inherently smaller and cheaper than the corresponding 60-cycle motor. This is a fundamental difference. On the basis of equal costs of motors, with quite different power factors, additional cost of power factor correction should be included to make the two entirely comparable. It is, however, only in the low-speed induction motors that the 25-cycle frequency represents any material advantage. If, therefore, a plant should be made up largely of low-speed induction motors, the 25-cycle frequency would represent a most nearly ideal arrangement. However, there are very few plants, if any, where the larger part of the total power is utilized in such motors. Therefore, taking all the other service into account, it will probably be found that there are very few plants where 60 cycles cannot now make practically as good showing as 25 cycles. In other words, where the low-speed service represents but a relatively small part of the total service, it may be better to make some sacrifices in this smaller part to the advantage of the whole.

The question of purchase of 60-cycle power is dependent, of course, upon many conditions. In the Pittsburgh district, for instance, the total electric power used in the various steel mills may represent the equivalent of a huge power plant in itself. In consequence, if the various mills were to combine their power plants into one general plant, the capacity of such plant and the conditions of operation would probably be such that it could compete quite favorably with any large central station, and in such case 25 cycles could be the frequency. Moreover, this would remove the manufacture of power from the mills themselves and place it in a plant whose sole business would be the manufacture and supply of electric power. It may be suggested at this point, that, at present, furnace gases are used to a greater or less extent under the boilers for power plants and that with the power plant placed elsewhere these gases would be wasted. However, there is not much doubt but that other uses would be found for such gases, and, in fact, some of the steel mills at present can find uses for all the furnace gases without burning them under the boilers.

However, in considering a single large power plant, the Pittsburgh district represents very unusual conditions in that there is a concentration of many huge steel plants within one relatively limited district. A combined steel power plant in the Pittsburgh district would, therefore, represent a very special rather than a general condition and would furnish the solution of the problem for only one general district. In other districts the problem of 60 cycles versus 25 cycles would still hold and would have to be met. Therefore, it is the general problem rather than a special one which should be considered broadly.

With this question of purchase of power before them, a number of the steel mills throughout the country which have been planning to increase their power plants, are faced with the question of installing additional plant at 60 cycles instead of 25 cycles; also, with their existing 25-cycle plants, the purchase of additional power at 60 cycles involves numerous problems in the application of such power to the existing equipment. Various suggestions have been made from time to time as to how to handle this situation in its various forms. Probably as good a way as any to look into the problem would be to classify the various methods by which the double-frequency situation could be met. These methods may be given as follows, the order in which they are given, however, not representing their expediency or importance.

1. Rebuilding, or allowing to become obsolete, the existing plant and replacing entirely with 60 cycles.

2. Conversion of 60-cycle purchased power to 25 cycles by frequency-changers and operating in connection with existing plants. This retains the advantage of the existing 25-cycle system but means, however, considerable losses due to the frequency-changers.

3. Allowing the existing 25-cycle plant to remain in service, and installing new generating and motor equipment for 60-cycle. This would allow purchased 60-cycle power to be utilized in connection with the new generating plant. This, however, involves a more or less mixed system throughout the plant.

4. Retaining the existing 25-cycle plant for those parts of the service where 25 cycles is materially better, and changing other parts to 60 cycles for use on purchased power. This could be continued until the old plant and equipment became obsolete. This would probably mean a mixed system throughout the mills for years to come.

5. Utilizing the existing plant within certain areas and applying 60-cycle purchased power to extensions and new areas. This involves a double system, but not a general mixture of two systems in the same areas. Eventually if the purchased power proves more satisfactory than the local supply, the latter could gradually become obsolete. This means, however, that in the new areas the 60-cycle frequency would be applied to low-speed motors as well as all other apparatus.

Looking at the matter broadly, it does not seem advisable to generate two separate frequencies in the local plant. In other words, if 25 cycles is the existing frequency, it is not desirable to put in an additional generating plant at 60 cycles, unless such new equipment is to be of greater capacity than that already installed. In this latter case it might be advisable to put in the additional plant of 60 cycles, simply with the understanding that the older small 25-cycle plant will soon be superseded entirely. In other words, the only condition under which the two frequencies should be mixed in the one generating plant, is where one of them is to be abandoned entirely within a reasonably short time. Wherever the additional plant, however, is to be less in size than the plant already installed, or simply represents the normal growth, then it appears that it would be better to put in the additional plant at the same frequency, rather than mix the two frequencies.

Some of the large central stations throughout the country have encountered a similar problem. In some of these cases both 25- and 60-cycle generating units have been installed in the same power plant, but as a rule, they supply quite different service and areas. For instance, the 25-cycle service will be utilized almost entirely by conversion to direct current, and within a given district this will apply exclusively. In other cities the 60 cycles may be represented by entirely separate power plants supplying outlying districts mostly, a large part of the application being by direct service instead of by conversion to direct current. As far as the writer knows, in general, the two services are not mixed indiscriminately. In the earlier days where 60-cycle service came into considerable demand in connection with 25-cycle plants, frequency-changers for giving 60 cycles were installed in many cases. As the 60-cycle service grew, instead of adding more frequency-changers, whose sole function is to change frequency, not to generate power, the practise has been to install 60-cycle generating units often in separate power plants, the existing frequency-changers then being used as a tie between the two plants. In those cases where the capacity of the two power plants has been very considerable compared with the capacity of the frequency-changers tying them together, there have been certain conditions of unusual stresses in the frequency-changers at times of severe load conditions. In other words, if the link, tying the two plants together, is a relatively weak one, sometimes it may be broken. This problem of the two frequencies has been one of long standing with the central power stations, and as the present solutions are more or less a development from experience, this is possibly an indication that steel mills should follow along somewhat similar lines.

It has been suggested that in the application of 60 cycles to steel mills, this might be used largely for one kind of service such as the motor-generators or synchronous converters, for producing direct current. In this way the 60-cycle service need not be distributed so generally throughout the mills, but would simply be supplied to the converting machinery which is not scattered through the mills in the same way as the motors. Moreover, the modern 60-cycle synchronous motor-generator is just as cheap and economical as its 25-cycle competitor, or cheaper in some cases, while the 60-cycle synchronous converter, if transformers are included, approaches pretty close to the 25-cycle in general operating characteristics.

In existing mills, however, changing to 60 cycles would mean replacing or remodeling, at very considerable expense, the existing motor-generators and synchronous converters, and unless the future growth of such apparatus is to be very large compared with that already installed, this reconstruction or replacement might prove in the end to be relatively expensive, perhaps as much so as the installation of frequency-changers, which would allow the continuation of the existing 25-cycle frequency. Even if the existing machinery is more or less out of date, unless it has uneconomical characteristics, it can probably be kept in service for many years to come, for much of this machinery is well built and of durable construction and may still have twenty to thirty years of good operative life. In fact, some of the motor-generators and synchronous converters which have been in operation for ten to twenty years in steel mills appear to be as good as when first installed, and it will be difficult to justify their obsolescence and replacement.

Something might be said further regarding frequency-changers. As stated before, the function of the frequency-changer is simply to change frequency at a considerable expense in power. There are other objections outside of inefficiency which count against the frequency-changer, but these probably would not be dominating or controlling in themselves. On the face of it, the frequency-changer seems to furnish such a simple solution of the frequency problem that in some instances it might pay to sacrifice other considerations in favor of simplicity.

It must be kept in mind, that there are no means for getting the exact 60 to 25 relation with an economical type of machine, for the numerical ratio of 60 to 25 only allows a 24-10 pole combination, which represents a rather low speed except for units of enormous capacity. If any other more economical combination of poles is chosen, such as 10-4 or 14-6,

then, with a 60-cycle supply system, some other frequency than 25 cycles will be obtained. The 10-4 pole combination gives 24 cycles, while the 14-6 pole combination gives 25.7 cycles. Therefore, for either of these combinations, it would be necessary to change the steel mill frequency slightly, for it would be almost impossible to get any general power company to change its frequency of 60 cycles. Naturally, if either of the above combinations were to be adopted, the 10-4 pole would be preferable from the standpoint of the frequency-changer itself. However, there might be some question regarding the use of 24 cycles instead of 25 cycles in steel mill applications, for this means a general reduction of 4 per cent in the speed of all synchronous and induction motors. Thus the choice of the most advantageous speed for the frequency-changer may possibly represent a material disadvantage in the motor equipment. Again, the use of the 14-6 pole frequency-changer would mean increasing the mill frequency about 3 per cent, which should not be as objectionable as a reduction of 4 per cent. However, the 14-6 pole combination would not represent nearly as cheap frequency transformation.

As affecting the cost of the frequency-changer and its losses, there may be considerable saving over the installation of corresponding capacity in additional power generating plant. In installing new or additional power plant, the cost of the electric machinery represents but a small part of the total cost and, unquestionably, the extra buildings and equipment, to go with the frequency-changer, would be very materially less than that of additional generating plant. This saving in first cost, in some cases, might go a long way toward offsetting the losses of the frequency-changer, especially in those cases where 60-cycle power can be obtained at a very low rate. However, no definite statement can be made as to the comparative costs, because each case would have to be worked out individually.

As soon as two or more frequency-changers are to be installed in one plant, these to be operated in parallel with each other and with the existing generating plants, then complication comes in, possibly to such an extent as to lose most of the simplicity of the scheme. The synchronizing and proper paralleling of two or more frequency-changers with each other and with their respective power plants, is one of the "fussy" things which can be carried out successfully, but which nobody likes.

Attention should be called to the fact that if any particular combination of frequency-changer sets is chosen such as represented by 10-4 poles, or by 14-6 poles, then this exact ratio must be retained throughout, if additional frequency-changers are ever to be added to the plant. It is obviously impossible to parallel two combinations of poles which do not have the same ratio.

As to the capacities of such apparatus which are practicable in single units, 10-4 pole sets of 5000-kv-a. capacity have been offered recently by manufacturers. However, for larger capacities than 5000 kv-a. certain difficulties arise, as the next possible pole combination is 20-8, which represents just half the speed. In consequence, even with a 10,000-kv-a. set, halving the speed will probably more than offset the gains in cost and efficiency resulting from larger capacities. One would assume, in consequence, that two 5000-kv-a. units would be preferred to one 10,000-kv-a., and presumably this is correct, if the two units can be operated independently. For parallel operation, however, the added complexity might be considered sufficient to offset a slight increase in cost of the larger single unit.

For costs and efficiencies of such apparatus, the following very approximate figures are suggested.

For a 5000-kv-a. set including auxiliaries, switchboard appliances, etc. from \$10.00 to \$11.00 per kv-a. The combined efficiency will be approximately 92 per cent or better at full load and 89 per cent or better at half load.

For a 10,000-kv-a. set, having 20-8 poles, the cost per kv-a. could be taken roughly at \$11.00 to \$12.00. No figures for efficiency have yet been worked out.

Neither of the above approximations includes cost or efficiency of step-down transformers.

There is one other class of electric machinery used in steel mills where the effect of frequency has not yet been considered, namely, in the induction-motor speed-regulating sets which are coming into use to a considerable extent in recent years. There are three types of such speed-regulating appliances in use today, all of them requiring commutating machinery, namely, (a) those in which the secondary electrical power of the induction motor is transformed into mechanical power and utilized as such; (b) where the secondary electrical power is transformed into direct current and utilized; and (c) where the secondary power is transformed from the variable or adjustable frequency of the secondary to some fixed frequency such as that of the line and thus utilized. The first of these schemes involves polyphase commutating type motors; while the second requires synchronous converters; and the third requires commutator type frequency-changers, which are a more recent development than the other types of machinery mentioned.

From the standpoint of commutation, (a) and (c) present considerable advantages in first cost, general performance and efficiency at 25 cycles, as compared with 60 cycles, while method (b), involving synchronous converters, makes its best showing at 60 cycles, although all three arrangements are praticable at both frequencies. Arrangements (a) and (c) allow satisfactory operation both above and below the synchronous speed of the induction motor; whereas, (b),

heretofore, has only been worked below synchronism, although auxiliary means may be found for this scheme just as with the other two, for successfully passing the synchronous speed condition. All these methods of speed control will doubtless be used to a considerable extent, depending upon the conditions and the applications, but as they can be operated successfully on both 25 and 60 cycles, apparently they will have no controlling influence on the choice of frequency.

In conclusion, it may be said that there is no good general solution to this frequency problem and each case must be handled on its merits, taking the future tendencies and growths into account. In many cases it appears that the large existing 25-cycle local systems should be retained at least until such time as the need for replacement is more obvious than at present. Unless the future service of the mill shows strong inclinations of going almost entirely to 60 cycles a mixed generating plant is not to be recommended. In those cases where existing 25-cycle power and purchased 60-cycle power are both to be used, they should at first have their own individual services or areas, as far as possible, to avoid indiscriminate mixing of services throughout the mills, and to avoid frequency-changers, with their attendant losses, unless conditions are such as to warrant their use. In general, where both frequencies are liable to be used for some time to come, and there is any real necessity for a tie between the two, then frequency-changing becomes a necessity. However, as central station service has now become quite reliable there is not the need for a tie between two frequencies that was formerly the case, so that doubtless, in many cases, frequency-changers can be dispensed with. In case of a new plant, even where it expects to generate its own power, in general it should be installed at 60 cycles, if *located in a 60-cycle district,* simply on account of future possibilities. There is no question whatever that future central stations will supply power for general purposes, at 60 cycles, within certain large districts, the trend being too strong to be changed or controlled. In other large districts it will be principally at 25 cycles, as in the territory served by Niagara, for instance. There will be still other cases where both frequencies will be used, simply because the field for 25 cycles is already so large that 60 cycles cannot replace it. In New York City, for instance, 25 cycles is already in use on such a vast scale (1,099,600 kv-a., 25 cycles, and 217,000 kv-a., 60 cycles) that it may be almost a lifetime before the 60-cycle service overtakes it. But the present growth in 25 cycles appears to be limited to existing plants, many of which may never be replaced by 60 cycles. In consequence of this mixed service, the ultimate solution of the general supply problem may mean 60 cycles for general purposes with 25 cycles as an auxiliary supply. It may be assumed that in those cases where 25 cycles presents such advantages that the consumer will put in his own generating plant, if necessary, to obtain such service, that eventually the general power service will find some means for supplying the individual case.

FOREIGN PATENTS

Those inventors who have interest in foreign patents should note that at the present time many changes are being made in continental and other patent laws, which need to be watched if it is desired adequately to protect the inventions in Europe or in the greater part of the world. A new law has recently been provided in Jugo-Slavia which brings this matter into prominence. Protection of industrial property is now uniformly regulated for the whole of the kingdom of the Serbs, Croats and Slovenes, and all protections which have been obtained in any part of Jugo-Slavia, either in the former kingdom of Serbia, or in Austro-Hungarian territories, which were in force at the end of last year, must be re-filed if it is desired properly to protect the invention throughout the kingdom of Jugo-Slavia.

The provisions of the new law correspond largely with those of the old Austrian Patent Law, and therefore exclude from protection matters which are Government monopolies. It is not usually known in this country how far these monopolies extend, so that it is well, before deciding on any particular patent application to be lodged in the new kingdom, to inquire of authorized parties. Explosives, tobacco, certain kinds of paper, and petroleum are among the subjects for which valid patents cannot be obtained.

Among other countries in which modifications have been made in connection with Patent Laws recently there may be named Roumania, Esthonia, Greece and Hungary.—*The Engineer,* London.

GEORGIAN WIRELESS STATION

According to an issue of the Near East for February 3, 1921, the Georgian Ministry of Supplies has concluded an agreement with a French trading and financial company for the erection of a powerful radiotelegraphic station in Georgia, by means of which it will be possible to communicate within a radius equivalent to the distance between Tiflis and London. The new station will connect Georgia with large European centers, such as Paris, London, Rome, Moscow and others.

According to the agreement, the Ministry of Supplies is to pay for the erection of the station by means of a consignment of tobacco. The station is to be erected within the next six months. At the same time another agreement under the same conditions was signed for the erection of four wireless telephone stations in various parts of Georgia. The central wireless telephone station will be erected in Tiflis.

Carrier Current Telephony and Telegraphy

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Western Electric Co. American Telephone & Telegraph Co.

This paper briefly outlines first the history of the development of carrier multiplex telegraphy and telephony. The fundamental principles underlying particularly the newer developments of the art are then discussed. Consideration is likewise given to the propagation characteristics of open wire lines, including those containing intermediate lengths of cable. Commercial types of apparatus and actual installations are then described and a brief statement made as to further applications of the art.

THE carrier method of multiplexing telephone and telegraph lines is technically one of the most interesting and important of the developments which have been perfected in the art of electrical communications during the past few years. In this paper we are giving a brief sketch of the development of this art, an explanation of the principles on which it is based, and a description of the applications which have been made in the plant of the Bell Telephone System.

In a carrier multiplex system, a number of separate telephone, telegraph or signaling messages are superimposed simultaneously on a single electrical circuit by employing a separate alternating current, usually called a "carrier current," for each of the separate messages. This carrier current is made to vary in accordance with the variations of current representing the telephone, telegraph or signaling message. The different carrier frequencies which are superimposed on a circuit must differ sufficiently in frequency so that they may be separated from each other at the terminals by the use of proper electrical circuits. Each carrier may be of either audible or ultra-audible frequency, but its frequency must be higher than the highest frequency represented in the message to which it corresponds. These currents are known as carriers, since in a sense, they may be said to "carry" the telephone, telegraph or signaling currents by which they are controlled.

The underlying principles of such systems are old in the communication art and indeed go back to the date of the invention of the telephone itself, for it will be recalled that it was Bell's experiments with the vibrating reed type of multiplex telegraph system which led to his discovery of the telephone. A short history of the art during the forty odd years that have elapsed between the conception of its possibilities by the early communication pioneers and the present realization of their hopes is given below under the heading "Historical."

In looking back over the early history of the carrier art it is now clear that the development of successful multiplex carrier systems had necessarily to await not only the evolution of the fundamental ideas for carrier operation, but also the development of radically new types of apparatus and the developments in electrical wave transmission over wires which have characterized the recent progress of long-distance telephony.

The telephone and telegraph systems which are described in this paper are in daily use over long toll circuits in the Bell telephone system. The telephone installations in service furnish simultaneously as many as four two-way telephone conversations over each circuit in addition to the telephone and telegraph facilities normally afforded by the circuit. The telegraph systems in service are arranged to furnish as many as ten duplex carrier telegraph circuits over each circuit in addition to the telephone and telegraph facilities normally afforded by the circuit. These figures do not indicate the maximum numbers of facilities which it will be found economical to employ ultimately, but cover the facilities furnished by the systems which are now commercially employed.

The increased circuit facilities obtained in this way are, in general, up to the high standards set for the best grade of long-distance circuits. They are relatively stable and are maintained by the regular telephone plant personnel. The carrier circuits, both telephone and telegraph, are so designed that as circuits they fit in completely with the more usual circuit facilities of the telephone system. They may be connected with each other and with ordinary circuits, and, in general, present much the same degree of practicability and flexibility of operation as do the more usual forms of circuits.

While the development has thus succeeded in making available to the communication art new types of circuit facilities, these facilities can only be made to meet the high standards required in a public service plant by the use of correspondingly high-grade equipment which, unfortunately, is correspondingly expensive. Indeed, the cost of these systems, at least at present, is such as to make their use economical only over relatively long toll circuits. For short-distance toll service, and for local exchange service, the equivalent facilities can be provided more cheaply by the older methods.

Historical

As indicated above, the multiplex carrier art had its origin in the harmonic telegraph systems dating back to the time of the invention of the telephone itself. With such alternating-current telegraph sys-

Presented at the 9th Midwinter Convention of the A. I. E. E., New York, Feb. 16-18, 1921.

tems are associated the names of Gray, Bell, Van Rysselberghe, Edison and Mercadier. The multiplex feature of these systems is well illustrated by Fig. 1, which is a reproduction of a diagram of Elisha Gray's system published[1] in 1886.

In this figure, the circles numbered 1, 2 and 3 represent vibrating reed transmitting instruments

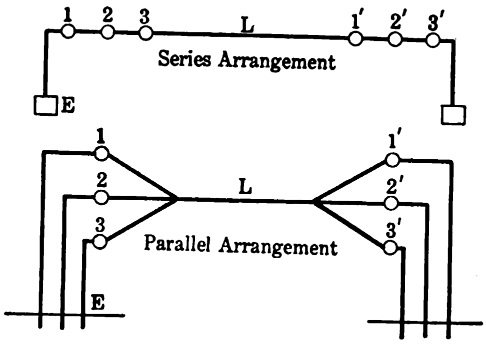

Fig. 1
(Multiple Harmonic Telegraphy)

while those numbered 1′, 2′ and 3′ represent the corresponding receiving electromagnetic reeds. When one of the transmitting reeds is vibrated, the electrical waves sent out set into oscillation the correspondingly tuned receiving reed which thus gives out an audible note. The systems invented by these pioneers are all characterized by the use of the mechanical resonance of tuned reed instruments for generating and selecting the carrier frequencies involved. This type of system has been more fully developed by Mercadier.

The Art of the 1890's. Shortly after 1890 there occurred the next outstanding development in this art, namely, the use of electrical resonance instead of

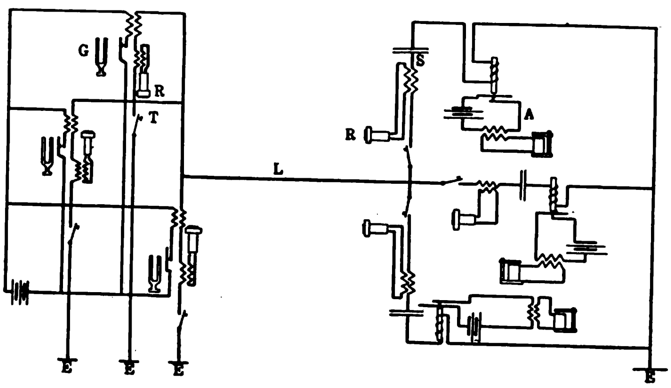

Fig. 2
(Pupin—1892)

mechanical resonance for selecting the carrier frequencies. An interesting piece of technical history is disclosed in the manner in which several investigators, Professor Pupin, Hutin and Leblanc, and John Stone Stone, independently invented about the same time the electrical method of selection of a plurality of carrier frequencies. Pupin was adjudged the earliest inventor in the United States. His original system is illustrated in simplified form in Fig. 2.[2]

In order to permit the successive figures in this historical discussion to be readily followed, a uniform system of lettering their important parts has been employed. These conventions are as follows:

G = Generator of carrier current.
T = Telegraph key, telephone transmitter or other carrier modulating device.

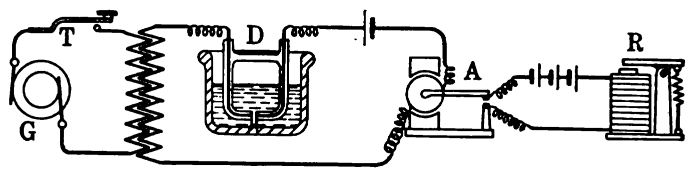

Fig. 3
(Pupin—1898)

L = Line.
S = Selecting or tuned circuit.
D = Detector.
A = Amplifier.
R = Receiver.
D R = Detecting receiver.
E = Earth.

By following this lettering Fig. 2 will be readily understood. It will be noted that at each end the line branches into three parts, and that each circuit is tuned by capacity and inductance to a particular frequency. It will be seen, furthermore, that each of the channels derived in this manner is arranged for sending in both directions, although not simultaneously. Each generator consists of a self-excited tuning fork driving a contact or a microphone transmitter. Re-

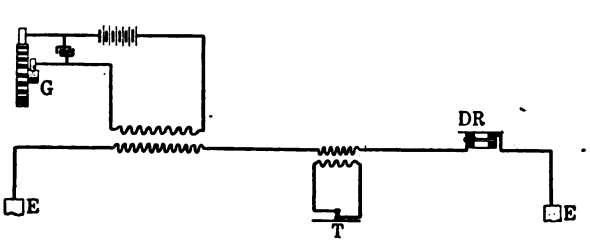

Fig. 4
(Hutin and Leblanc—1892)

ceiving is accomplished either by a telephone receiver or by a vibrating reed device which is operated by a microphone amplifier.

Pupin also invented an electrolytic detector for use in such alternating-current telegraph systems as shown in Fig. 3.[3]

The function of this detector was to rectify the alternating current and thus enable a d-c. telegraph relay to be operated from the rectified current. This marked the beginning of the use of separate

1. Leblanc, M., "Le Telephone Multiplex," *La Lumiere Electrique*, p. 97, Apr. 17, 1886.

2. From U. S. Pat. No. 707,007, 1902.
3. From U. S. Pat. No. 713,044, 1902.

devices for performing the two primary functions of carrier receiving; (1) that of reproducing from the carrier the current variations which represent the original signals, and (2) that of indicating the signals, as by a relay or telephone receiver. The separation of these two functions is important in the carrier art because it permits the place at which detection is effected to be separated from that at which the indication or interpretation occurs.

While the contributions up to this time were concerned primarily with telegraphy, they were very soon carried over into the field of telephony (still in the early 90's) by such pioneers as Gibboney, Hutin and Leblanc, and Stone. Their predecessors were concerned with the use of carrier frequencies of the order of a few hundred cycles, whereas, these inventors appreciated the necessity of employing for telephony carrier currents sufficiently high in frequency to preserve the characteristics of the voice currents. Thus we find suggested at this early date the use of carrier currents in the tens of thousands of cycles, which values have since proved to be in the preferred frequency range. Hutin and Leblanc so simply illustrated the use of relatively high-frequency alternating currents for telephony that it is useful to reproduce their early diagram as shown in Fig. 4,[4] for the purpose of obtaining in our discussion an appreciation of the principles involved.

This is a carrier telephone circuit of the simplest type, arranged for a single one-way transmission. Connected in the line are three elements, the generator of the high-frequency currents *G*, the voice-actuated modulator *T*, and the detector-receiver *D R*. The generator is a high-frequency commutator; the modulator is a microphone transmitter; and the receiver which is of the dynamometer type serves the double function of detection and of translation into sound waves.

Multiplex operation of this type of carrier telephone channel as devised by these French inventors at the same time (about 1892) is also representative of these early contributions to carrier telephony and is reproduced in Fig. 5[5]. Here we have the carrier telephone channel of Fig. 4, arranged for multiplex operation by the use of electrical selection, each of the carrier circuits being tuned by capacity and inductance to its own carrier frequency.

As indicated the carrier currents of all the channels are introduced into the line at a common point through a transformer. At each terminal the line divides into four branches. Each sending branch contains a microphone transmitter *T* connected into circuit through a transformer. Each receiving branch contains a dynamometer receiver *D R*. The condenser in each transmitting circuit and the inductance in each receiving circuit were employed in tuning the channels.

The multiplex system invented by John Stone Stone[6] was very similar to those illustrated above for Pupin, and Hutin and Leblanc, and is therefore not illustrated. It did, however, contain an important improvement over those of his contemporaries in that he tuned the local branch circuit individually instead of tuning the system from end to end for each

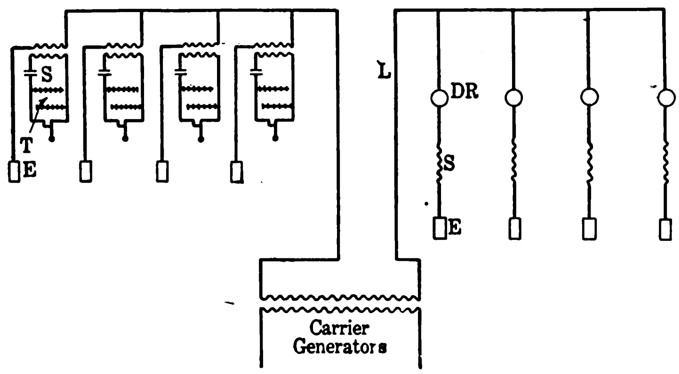

Fig. 5
(Hutin and Leblanc—1892)

carrier channel, as did Pupin, and Hutin and Leblanc (see their figures). This improvement is evident also in a system which he developed shortly afterward, especially for high-frequency transmission. This is illustrated in Fig. 6.[7]

Stone devised and tested this system in the laboratories of the American Bell Telephone Company in 1894. The high-frequency currents were generated by means of small arcs which were fed from a d-c. source through a suitable choke coil. One of the electrodes

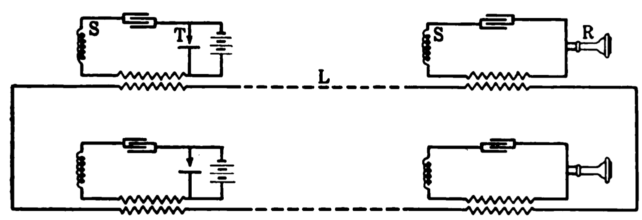

Fig. 6
(Stone—1894-96)

of each arc in Fig. 6 was made light in weight and was attached to a diaphragm which served, when acted upon by voice air waves, to modulate the high-frequency currents generated by the arc. The particular arrangement illustrated is also of interest in showing the tuned circuits at both the sending and receiving ends as associated with the line in a series manner, an arrangement which is an alternative of the parallel connections previously illustrated.

It is also of interest to note in connection with these

4. From U. S. Pat. No. 596,017, 1897, British Pat. No. 23,892, 1892, French Pat. No. 215,902, 1891.

5. British Pat. No. 23,982, 1892; French Pat, No. 215,901, 1891.

6 U. S. Patents Nos. 726,368, 1903; 726,476, 1903; 729,103, 1903; 729,104, 1903.

7. From U. S. Pat. No. 638,152, 1899.

older multiplex telegraph systems that Van Rysselberghe recognized as early as 1886[8] the advantage of superimposing the alternating-current circuits on an ordinary d-c. telegraph circuit, thereby enabling the ordinary telegraph wires to be employed for the transmission of the multiplex system. While the idea of extending the range of frequencies employed in

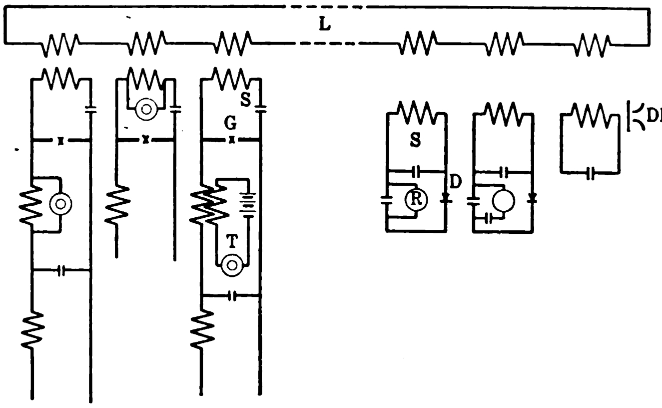

FIG. 7
(Ruhmer—1909-10)

the multiplex system down to zero frequency and thereby including the d-c. signaling circuit would naturally be obvious in a more advanced stage of the art, its invention at this early date illustrates the clear engineering appreciation these earlier inventors possessed.

It will be seen, therefore, that the foundation of the carrier art was laid back in the 1890's, at which time there had been contributed these cardinal features:

1. Electrical selection or tuning.
2. The use of continuously generated high-frequency carrier currents.
3. Modulation of the carrier, as by a microphone transmitter.
4. Detection and indication of the high-frequency currents by means responsive continuously and proportionally to the received current.

Relations of Radio Developments. With the entrance of wireless telegraphy into the communication field, the attention of those scientists and engineers who might otherwise have developed the art of wire multiplex, so well begun, as indicated above, seems to have been diverted to the new found art. The wireless art started with the use of very high frequencies, generated discontinuously by the spark method, and gradually came to use waves of lower and lower frequency, and of increasing persistency. Finally, with the use of continuously generated waves, the radio-frequency range came to overlap the frequency range earlier employed in high-frequency wire transmission. The wire carrier art started with the use of audible frequencies and extended into the ultra-audible range, where it was later met by the radio frequencies. The similarity of the history of the two developments is illustrated by the fact that the major steps, which are noted above for the early carrier art, also mark the major steps of advancement of the radio art. By reading over the four points above, keeping radio in mind, the parallel will be seen to be quite complete.

These ideas of continuous wave telephone transmission were quite thoroughly appreciated in the radio art by about 1905, although they have not been fully attained in practise until quite recently. It was natural that radio engineers should carry these ideas over to wires, using radio instrumentalities which, while different in form, operated on the same principles as did the means employed by the earlier wire pioneers.

Simultaneously with this evolution of the radio art, attention continued to be given to the older wire carrier transmission by such other investigators as Vreeland in America and Bela Gati and Maior in Europe. About 1906 Vreeland, using his well-known mercury-vapor oscillator as a generator of sinusoidal carrier currents, devised a multiplex carrier telegraph system which embodied improvements in the use of loosely coupled tuned circuits in proper relation to the impedance of the line. An engineering and commercial development of this period, as distinguished from more purely laboratory or theoretical investigations, was the so-called "Phantoplex" system devised by engineers of the Postal Telegraph Company and quite extensively employed by that company. In this system a relatively low-frequency carrier telegraph channel was superposed on the ordinary direct-current circuit. In addition to the above, attention may be called to the disclosures by Ehret and Kitsee. Ehret shows[9] a multiplex carrier telephone system including amplifiers, and Kitsee shows[10] a carrier telegraph channel operating over an ordinary telephone circuit.

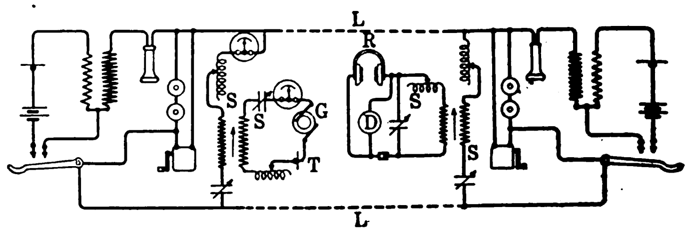

FIG. 8
(Squier—1910)

Previous to 1910, Dr. Ruhmer in Europe had undertaken experiments on high-frequency wire transmission, employing apparatus taken from the then current radio art. Ruhmer's system[11] is illustrated in Fig. 7.

8. U. S. Patent No. 363,188, 1887.

9. U. S. Pat. No. 789,087, 1905.

10. U. S. Pat. No. 666,883, 1901.

11. Belgian Pat. No. 224,008, Mar. 31, 1910; *Zeitschrift fur Schwachstromtechnik* of February, 1911; *Electrical Review and Western Electrician*, July 1, 1911.

He employed oscillating arcs as high-frequency generators, microphone transmitters as modulators, tuning at both the transmitting and receiving ends, and a radio detector in the receiving circuit.

In 1910 and 1911 Major, now Major-General, Squier carried out a set of experiments employing a carrier channel operating over a short telephone cable circuit. The announcement of his work popularized interest in this art, and the paper which he presented before the Institute in May, 1911 brought out considerable discussion.

The system which he used in his experiments is illustrated by Fig. 8.[12] This figure shows a carrier telephone channel operating over the wires of an ordinary telephone circuit. A high-frequency alternator is employed to generate the carrier current, a microphone transmitter is used as a modulator, tuning is employed at the sending and receiving ends, and a radio detector is employed in the receiving circuit.

As a part of the evolution of the radio art, there was developed in its early and somewhat crude form a device which was destined to play an extremely important part, not only in radio, but in wire communication as well, that is, the thermionic tube. Originally invented by Edison, this device was first applied as a radio detector by Fleming about 1904. DeForest in 1906 made a vital contribution by adding the grid, and thereby laid the foundation for its use as an amplifier. The history of this very remarkable device is so well covered in recent technical literature that we will discuss it here only in connection with its specific application to the carrier art.

The preceding history brings us up to about 1912. About this time an important step was taken toward the adaptation of the vacuum tube as a non-distorting amplifier by the addition of a negative grid battery by Lowenstein.

Since the above date, in addition to the active developments which were carried out in the Bell System and are described below, certain other investigators have been working in this field, among whom may be mentioned the General Electric Company, U. S. Signal Corp Engineers, Lee DeForest and certain European investigators, especially in Germany and France. In the attached bibliography will be found references to the more important publications which have been made by such investigators.

Bell System Developments. The most important developments, which have occurred since 1912 and are principally the work of the Research and Development Departments of the Bell System, may be stated as follows:

1. Development of the thermionic vacuum tube into a reliable and stable instrument for amplification, modulation and demodulation.

2. Development of the electrical filter and an improved technique of separating electrical currents of different frequencies.

3. Development of the technique of transmission over wires, particularly in connection with repeater operation and of methods for overcoming interference between circuits.

4. Development and operation of commercial carrier systems.

In considering the above developments which have led to commercial operation, it should be appreciated that in order for a carrier system to be commercially successful, it must compete on equal terms with the ordinary types of wire circuits, that is, it must have the same degree of reliability and stability, and must give the same degree of privacy and the same freedom from interference. Moreover, the system must be capable of being readily maintained and must be arranged so that it may be used interchangeably in the ordinary manner with any of the facilities furnished by the plant. All of these conditions must be met at a cost less than that of the ordinary types of circuits for similar service.

Developments in Thermionic Vacuum Tubes. The development of the thermionic vacuum tube as an amplifying element in a telephone repeater has already been described before the Institute,[13] as has also its application to radio telephony.[14]

The success which attended these two lines of development indicated that in this one device was embodied the solutions of many of the controlling difficulties that had previously stood in the way of the commercial development of carrier systems. In connection with a resonant circuit, the vacuum tube provides a compact and reliable source of continuous oscillations of readily adjustable frequency. As an amplifier of both low- and high-frequency currents, it removes the necessity for excessive line currents. As a modulator and demodulator, it provides an ideal means of impressing the voice waves on the carrier current, and of restoring them to their original form at the receiving end. These tubes have, moreover, been developed into devices which are very stable and reliable in operation, and may be maintained with only routine periodic supervision.

Electrical Filters. Another development which has been of vital importance in the success of carrier telephone systems is that of the "band-filter" invented by G. A. Campbell.[15] Without such electrical filters, it would be impossible to utilize economically the relatively low-frequency range employed in the present carrier telephone systems, or to separate various channels in this range from each other or from the ordinary telephone and telegraph channels. The simple

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12. From Fig. 6 of Squier's A. I. E. E. 1911 paper. Also Fig. 1 of U. S. Pat. No. 950,356, 1911.

13. Gherardi and Jewett, A. I. E. E. Trans., pp. 1287-1345, 1919.

14. Craft and Colpitts, A. I. E. E. Trans., pp. 305-343, 1919.

15. U. S. Patents No. 1,227,113, 1,227,114, of 1917.

tuned circuits of the prior art would either introduce prohibitive distortion or, if made sufficiently non-selective to avoid distortion, would require placing the carrier channels widely apart in frequency. The Campbell filter, therefore, enabled the carrier channels to be squeezed closely together at comparatively low frequencies where the difficulties of transmission over lines are at a minimum.

Transmission over Wire Circuits. Since the attenuation over wire circuits is much greater at carrier frequencies than at the ordinary telephone frequencies, the successful operation of carrier systems is particularly dependent on the use of repeaters at comparatively frequent intervals in the line. This has required the development of high-frequency repeaters involving the application at high frequencies of all the developments of the repeater art which were described before the Institute in the paper on Telephone Repeaters already referred to. As in the case of telephone repeaters at voice frequencies, the amount of amplification which can be given by each repeater depends entirely on line conditions, such as the degree of line balance which can be maintained at the repeater point and the degree to which mutual interference between line circuits can be prevented.

This prevention of interference between line circuits required the development of more elaborate methods of transposing and adjusting them. In order to overcome the large transmission losses and irregularities introduced in open-wire lines by unavoidable sections of cable, new types of loading for cable circuits were developed for these carrier frequencies and put into practical use.

Development and Operation of Commercial Carrier Systems. In 1914, simple forms of carrier circuits, embodying the fundamentals of our present system, were successfully set up in the laboratory, and experiments carried out with them. In view of the favorable conditions which had resulted from the various developments noted above, it was decided to begin active work toward commercial carrier systems. Field measuring apparatus was developed with which the characteristics of existing telephone lines were carefully studied in the carrier-frequency range. At the same time in the laboratory the physical possibilities and limitations of the various types of apparatus and circuits were being studied. Based on these fundamental data there was developed in the laboratory a complete multiplex telephone system providing two-way telephone conversations, and operating over an artificial line. This laboratory apparatus was then taken into the field and tried out on a line between South Bend, Ind., and Toledo, Ohio. The practical difficulties always encountered were overcome, and satisfactory operation secured. At the same time satisfactory results were obtained on a simple type of carrier telegraph system between Chicago and Toledo.

The entry of this country into the war brought the work to a standstill for a time. However, the same cause created a demand for more telephone circuits between Washington and Pittsburgh. It was decided to meet this demand by a trial installation of a carrier telephone system between Pittsburgh and Baltimore, from which point cable circuits to Washington were available. In view of the urgency of the situation, the apparatus used in the earlier field experiments was adapted to equip the Pittsburgh terminal, while new apparatus was built for the Baltimore terminal. This carrier system went into service and has since been operating satisfactorily.

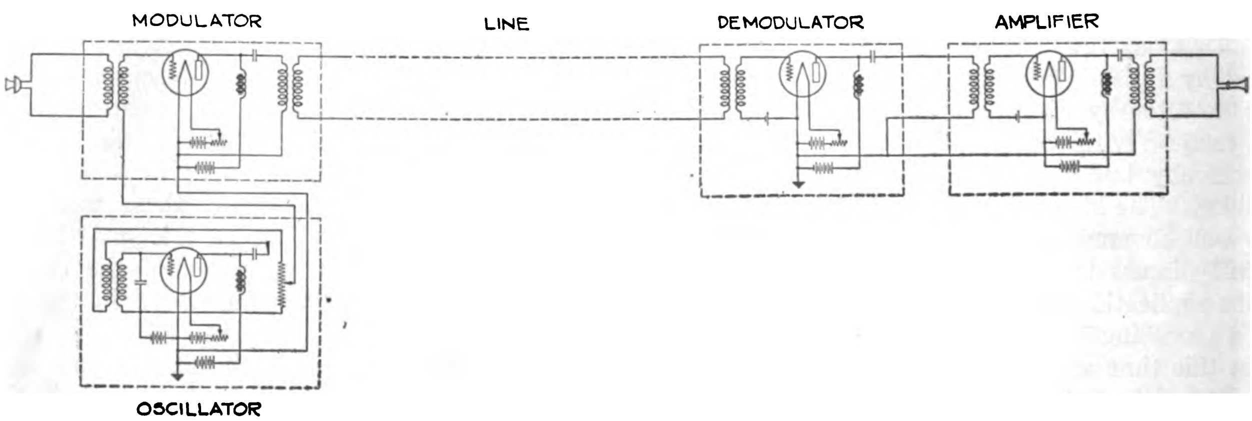

Fig. 9

Principles of Operation

General. An adequate understanding of carrier systems requires a consideration in some detail of the fundamental principles underlying their operation. Some of these principles, which are also important in connection with telephone repeater operation and in connection with radio telephony, have already been discussed at some length before the Institute in papers[16] on those subjects as referred to above. Emphasis will therefore be placed on those features which pertain more strictly to carrier operation.

16. Gherardi and Jewett, loc. cit.
Craft and Colpitts, loc. cit.

The underlying principles of carrier will be described in their application to carrier telephony. Their application to the somewhat different conditions of carrier telegraphy will be treated separately in a later section.

We will first discuss those features which are involved in a single one-way carrier telephone transmission channel, including generation of carrier current, modulation and demodulation or detection. Next will be considered multiplex operation in a single direction, involving separation of channels by selective circuits, followed by a consideration of two-way operation of single and multiplex channels. Next will be presented an explanation of another type of system in which no unmodulated carrier current is transmitted over the line and of a special mode of carrier current generation particularly adapted to this system. Finally the repeaters used for amplifying the currents of carrier frequency at intermediate points, and certain other matters such as ringing and the assignment of carrier frequencies will be discussed.

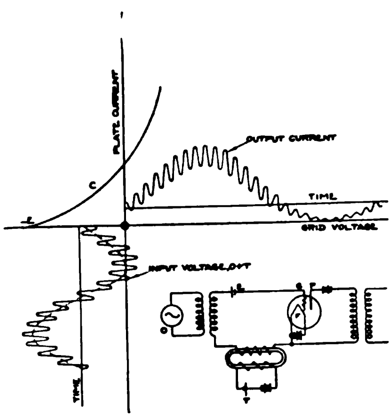

Fig. 10

Fig. 9 shows schematically the circuits involved in a single one-way channel. The source of carrier frequency shown is a vacuum-tube "oscillator." The operation of oscillator circuits in their many forms has been so thoroughly covered in the recent technical literature as not to require detailed discussion here.

Modulation. The process by which the carrier current produced by the oscillator is so combined with the voice currents from the telephone transmitter, that the variations of the latter are impressed upon the former, is known as "modulation," and the tube circuit in which this is accomplished is known as the "modulator."

It will be noted in the circuit shown that the potentials of carrier and voice frequencies are applied in series in the grid circuit of the modulating tube together with a steady voltage from a battery. Owing to the non-linear relation, which exists between the plate current and grid voltage, the output current of the tube is not simply a reproduction of the alternating voltages applied to the grid. In fact, the modulating properties of the tube result from the interactions between applied voltages which this non-linear relation introduces.

The mechanism of this interaction is shown graphically in Fig. 10, which is reproduced above from the paper on Radio Telephony already referred to.[17] It is evident that while the output current includes both the modulating current (here a sinusoid) and the carrier current, the amplitude of the latter varies in accordance with the instantaneous value of the former. Hence, even though the relatively low modulating frequency itself be removed by a selective circuit, its variations are preserved in the wave form of the higher carrier frequency. The form of this modulated carrier wave is shown in Fig. 11. Here curve *A* shows a modulating wave of irregular form representing the voice current, curve *B* the carrier wave, and curve *C* the modulated carrier wave, whose envelope has the form of the modulating wave.

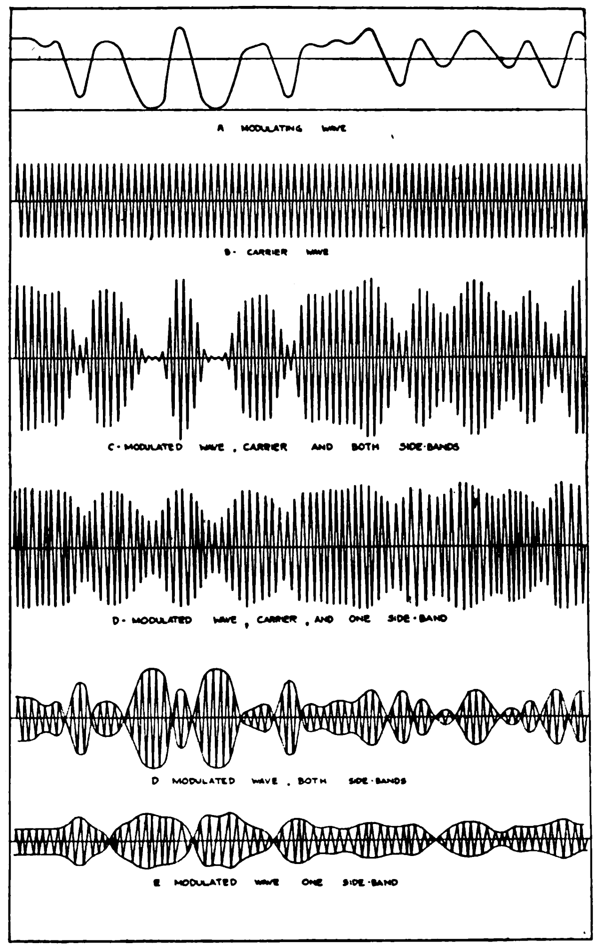

Fig. 11

As it is not at once obvious from an inspection of this modulated carrier wave what must be the frequency characteristics of a circuit which is to transmit it to a distant station, it seems worth while at this point to

17. Craft and Colpitts, loc. cit, page 312.

consider what component frequencies are present in the carrier wave and which of these are essential. The case is exactly analogous to that of attempting to design circuits for ordinary telephone transmission from a consideration of an oscillogram of a voice wave rather than from an analysis of its frequency characteristics. In the case of ordinary telephony, the problem has been solved by analyzing the voice wave into its components of various frequencies and ascertaining which of these frequencies it is essential to preserve and which may safely be neglected. This analysis has been accomplished largely in an experimental way through the use of electrical circuits selective to particular ranges of frequency. As a result of these experiments, it has been determined that speech of satisfactory commercial quality may be secured if the circuit is capable of transmitting all sustained alternating currents whose frequencies lie, let us say, between 200 and 2000 cycles per second. These limits having been determined, the apparatus may then be designed on the basis of its meeting these requirements as to the transmission of sustained single frequencies. The information accumulated at voice frequencies can be applied directly to the solution of the carrier current problem and, incidentally, to radio telephony, provided we know what component frequencies are present in the modulated carrier wave and what relations exist between these components and the component frequencies of the modulating or voice wave. For a complete discussion of the analysis of a modulated wave into its component frequencies, reference may be made to a publication by Carson[18]; and for its application to vacuum-tube operation to van der Bijl[19]. While it is known that a modulated wave can be resolved into a large number of component frequencies, it is necessary to consider here only those components which are directly involved in carrier transmission.

Assume for the moment the complex voice wave to be replaced by a sinusoidal current of a frequency $\frac{q}{2\pi}$ lying somewhere in the voice range. The envelope of the modulated wave will approach closely a sine curve and we may assume the value of the current at any instant to be given by the equation:

$$i = P\,(1 + k \cos q\,t) \cos p\,t.$$

This equation represents a carrier current of frequency $\frac{p}{2\pi}$ whose amplitude varies sinusoidally between the values $(1 - k)\,P$ and $(1 + k)\,P$; k being proportional to the amplitude of the modulating wave. By simple transformation, this may be resolved into its components, giving

$$i = P \cos p\,t + P\,\frac{k}{2}\,[\cos\,(p + q)\,t + \cos\,(p - q)\,t]$$

The first term represents a component of carrier frequency whose amplitude, P, is altogether independent of q and of k; and therefore it has no part in conveying the characteristics of the modulating wave to the distant station. These characteristics are preserved by the remaining two terms, whose frequencies are respectively the sum and difference of the carrier and modulating frequencies, and whose amplitudes are proportional to the product of the carrier and modulating waves.

From this it follows that every component frequency of a modulating voice wave is represented in the corresponding modulated carrier wave by two components, one of which is greater in frequency than the carrier wave by the frequency of the voice component, and the other of which is less by the same amount. We may therefore be certain that all of the essential components of the voice wave will be preserved if those components of the modulated wave are transmitted whose frequencies lie within two frequency bands, one of which extends from the carrier frequency plus 200 upwards to the carrier frequency plus 2000 and the other from the carrier frequency minus 200 down to the carrier frequency minus 2000. These are known as the upper and lower side bands, respectively.

While the above discussion refers more specifically to the use of the vacuum tube as the means for effecting modulation of a carrier current, it should be understood that any device possessing a non-linear current-voltage characteristic will operate more or less effectively as a modulator.

Demodulation. By the term "demodulation" is meant the process of reproducing the original low-frequency modulating wave from the carrier wave upon which it has been impressed. Various methods of accomplishing this result have been known for many years, such as the use of the electrolytic detector of Pupin or of crystal detectors of various forms. All of these operate by virtue of their non-linear current-voltage characteristics. The instrument which has, however, come to be employed almost exclusively for this purpose is the three-element vacuum tube, and the following discussion presupposes its use.

For a concrete example of the use of the vacuum tube as a demodulator, reference may be made to Fig. 9, above, where at the receiving station a modulated wave is shown applied to the input circuit of a vacuum tube. This figure also shows a low-frequency amplifier in the output circuit of the demodulating tube. Because of the bearing of demodulation on the transmission requirements of the system as a whole, we will discuss this matter at some length. Anyone

18. *Proceedings I. R. E.*, Vol. 7, page 187, 1919.
19. "The Thermionic Vacuum Tube," 1920, McGraw-Hill Book Co., Inc.

desiring to pursue the matter still further is referred to the publications[20] already cited under "Modulation."

The operation of the demodulating tube is exactly similar to that of the modulating tube, in that if voltages of two different frequencies are applied to its input circuit, there appears in its output circuit, a complex current wave. When the output current wave is resolved into its components, we find currents identical with the two frequencies which had been applied to the input, one component whose frequency is the sum of the applied frequencies, one component whose frequency is the difference of the applied frequencies, and a large number of harmonics and sum and difference frequencies. The amplitudes of the two currents whose frequencies are the sum and difference of the applied frequencies are proportional to the product of the amplitudes of the applied voltages. When, therefore, the received modulated wave is applied to the demodulating tube, we may determine the frequencies and relative amplitudes of the components of voice frequency in the output circuit of the demodulator by considering the interaction of the various pairs of frequencies in the modulated wave.

Obviously frequencies in the voice range can occur in the demodulator output circuit only as the difference of two components of the modulated wave. If we subtract the carrier frequency from any component of the upper side band, the result is the original speech frequency which produced that component. The interaction of the carrier and the entire upper side band therefore reproduces all the components of the voice wave with their proper relative amplitudes, since the amplitudes of the side band components are proportional to those of the original voice components, and that of the carrier is the same for all of them. The reproduction of the original voice wave also results from the interaction of the carrier with the lower side band.

It is evident that since speech can be reproduced from either side band alone, there is no necessity for transmitting both. Accordingly, the selective circuits to be described later can be so designed as to transmit only one side band. As this effectively halves the range of frequencies assigned to each channel, its great importance is at once obvious. The effect on the wave form of suppressing the upper side band is shown by curve *D*, Fig. 11. It is seen that in addition to the form of the envelope being changed, the times at which the current passes through zero are no longer equally spaced.

It is necessary to consider the interactions between the frequency components of the side band itself, for if, in the case of telephony, the voice wave includes components of more than one frequency, each will be represented by a corresponding component in the side band. The interaction of two of these component frequencies, simultaneously present in the side band, gives rise to a component in the output circuit of the demodulator, the frequency of which is the difference between those of the corresponding two components of the original voice wave. Such currents will have a serious effect on the quality of the reproduced speech, if their amplitude is comparable with that of the reproduced voice currents. The amplitude of this distorting component is proportional to the product of the amplitudes of the two side band components, whereas the amplitude of each of the two components of the desired voice current is proportional to the product of the amplitudes of its corresponding side band component and the carrier. The reproduced voice current can be made large compared with the distorting current only by insuring that the carrier is large compared with every component of the side band. As a result of this, it follows that in order to secure good quality it is necessary that the greater

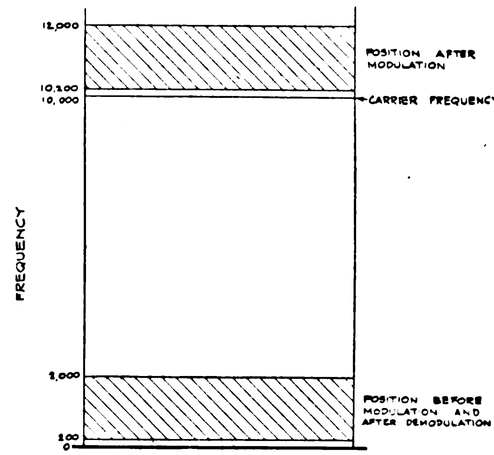

Fig. 12

portion of the energy applied to the demodulator consist of unmodulated carrier frequency.

The behavior of the receiving apparatus—that is, the demodulating tube—to interfering currents, such as may be produced by induction from external sources of electrical energy, so-called static interference, etc., can be directly deduced from the above considerations. With properly designed selective circuits only those line currents whose frequencies lie in the range of the side band being transmitted can reach the demodulator. These can produce noise of voice frequency either by interaction with the currents normally associated with that channel or by interaction with each other. Unless the interfering currents are of greater amplitude than the carrier current, in which case commercial operation is impossible, the noise components of the greatest amplitude result from the interaction of the interfering currents with the carrier current. The noise current in the output circuit therefore bears the same ratio to the reproduced voice current as the interfering line current does to the side band current. It follows,

20. Carson, loc. cit.; van der Bijl, loc. cit.

therefore, that in designing a system it is the side band current, in which are preserved the characteristics of the speech, which must at all points along the line be kept large compared with the extraneous disturbing currents lying within its range of frequency. This consideration has a very important bearing on the electrical design of apparatus operating on the carrier principle, whether dealing with wire or radio transmission.

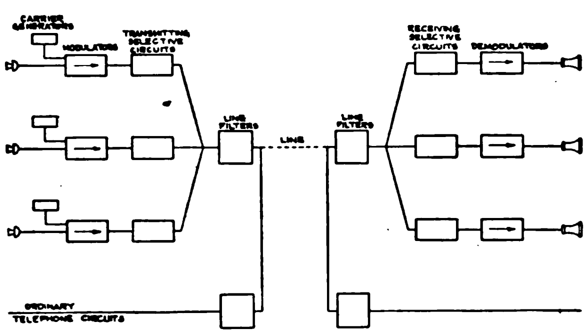

FIG. 13

While our discussion of modulation and demodulation has been made as concise as possible, it is evident from the foregoing that these two are complementary processes. Modulation may be thought of as elevating the band of essential speech frequencies to a position adjacent to the carrier frequency, and demodulation may be regarded as the process of restoring this band to its normal position in the frequency scale. In Fig. 12, the band of voice frequencies is shown, below, in its normal position before modulation, and above, in the position adjacent to the carrier frequency to which it is raised by modulation.

Selection—Electrical Filters. When a number of one-way channels of the type schematically shown in Fig. 9, each employing a different carrier frequency, are operated by superposition on a common line, each channel must be connected with the line through selective circuits which transmit only the range of frequency assigned to that particular channel. Not only must the demodulator assigned to a given channel be prevented from receiving from the line the currents of other channels, but the sending modulator must be prevented from putting onto the line currents of frequencies outside of its assigned band for, as was pointed out in the discussion of modulation, frequencies other than those desired are developed in the output circuit of the modulator, and if these currents were permitted to reach the line, those whose frequencies fell within the transmission band of some other channel would be transmitted to the demodulator of that channel through its receiving selective circuit. The general position of the selective circuits in such a one-way multiplex system is indicated in Fig. 13.

As will be brought out later in the discussion of the behavior of lines with respect to their transmission efficiency at carrier frequencies and with respect to cross-talk between adjacent circuits on a pole line, the most desirable frequency range is rather limited. For this reason, where it is proposed to secure a maximum number of channels simultaneously operating on a given circuit it is necessary to make the frequency interval between the adjacent carrier channels as small as possible. The first limitation to the frequency separation between carrier frequencies is determined by the fact that, as has already been pointed out, the width of the side band must correspond to the voice frequency range; that is, even with ideal apparatus the carrier frequencies must have at least a separation of approximately 2000 cycles per second. The ideal selective circuit which would permit this close spacing of frequencies is one which would transmit efficiently this side band, having a frequency range of 2000 cycles, and would absolutely block off frequencies outside of this band. Because it is not physically possible to secure such ideal circuits, we are obliged to make a greater separation in carrier frequencies than that made necessary by the width of the side band.

The nearest approach to this ideal selective circuit, particularly for carrier operation at moderate frequencies, is secured by the use of what has come to be known as an "electrical filter." This arrangement

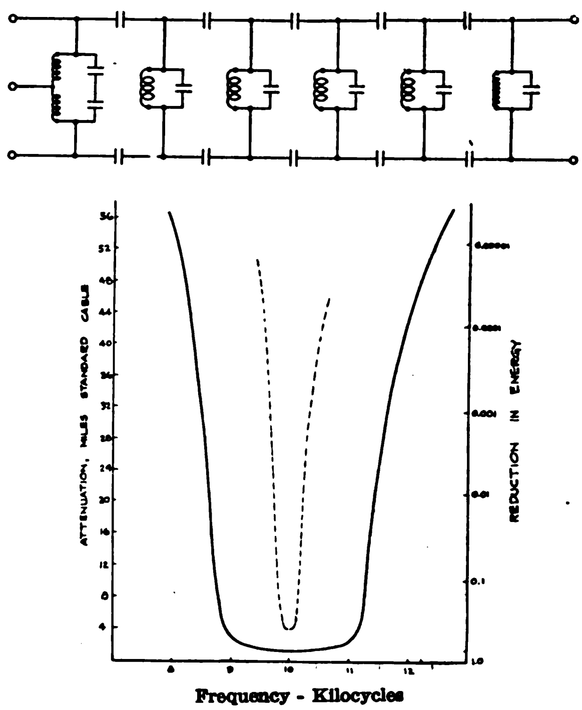

FIG. 14

was invented and thoroughly studied by Dr. G. A. Campbell even before practical carrier operation was made possible by the perfecting of vacuum tubes and the development of their use as oscillators, modulators and demodulators. Campbell's electrical filter is a network composed of inductances and capacities which transmits with a minimum of attenuation currents whose frequencies lie in a predetermined range and attenuates very greatly currents whose frequencies lie

outside that range. While these filters may take a variety of forms to meet special needs, they are all alike in that the currents traverse a succession of meshes or "sections," the attenuating effects of which are cumulative. The discrimination against the frequencies which it is desired to exclude may be increased to any physically practical value by increasing the number of sections.

Fig. 14 shows a type of filter which has been used to great advantage in carrier telephony. As this filter transmits a band of frequencies, it has, for convenience, been termed a "band-pass" filter. The transmission characteristics of this filter are also shown in Fig. 14, where the attenuation introduced into a circuit by the insertion of this filter is plotted against the frequency of the applied current. The attenuation is expressed in miles of standard cable. For the convenience also of those not familiar with this usage there is shown at the right a scale from which may be read for any frequency the fractional reduction of the energy due to transmission through the filter. This particular filter is designed to transmit the upper side band of a carrier of 9000 cycles or the lower side band of a carrier of 11,000 cycles.

At this point it may be instructive to compare the performance of the filter just described with that of a pair of loosely coupled circuits resonant to a frequency in the transmission band of the filter. The attenuation characteristics of such a tuned circuit are shown by the dotted curve in Fig. 14. It is obvious from the attenuations of this circuit in the frequency range of the side band that such a circuit is very poorly adapted to the purposes of carrier telephony.

Referring again to the band-pass filter above described, it is of interest to consider the relation between its attenuation characteristic and the operation of the system. The form of the attenuation curve within its transmission range is important from the standpoint of the quality of the transmission of the carrier channel in which the filter is used. If the attenuation is uniform throughout the frequency range which the filter is designed to pass, the effect is merely the same as that of increasing the length of line by a corresponding amount, and the loss can be compensated for by amplification inserted somewhere in the system. If the attenuation is not the same for all frequencies within the band, as, for example, if it is greater at the edges than at the center of the band, then the difference in transmission equivalent for different components of the side band will introduce a similar distortion into the over-all transmission frequency curve for various voice frequencies, as measured from the modulator input to the demodulator output. Such a distortion would manifest itself by more or less impairment in the quality of the telephone transmission.

Both the magnitude of the attenuation within the frequency band transmitted and the variation with frequency are dependent upon the dissipation of energy in the coils and condensers, as well as upon the choice of their electrical constants, so that the problem of securing filters of desired transmission characteristics has been largely one of obtaining reactance elements of high time-constants and of high accuracy and stability. For the capacities mica condensers are largely used. For the inductances a special core material of finely divided iron has been developed which has made possible toroidal iron-core coils which are superior in time-constant to air-core coils for frequencies up to the highest values used by us. At the same time they are more compact and have less stray field. Transformers having similar iron cores are also used throughout the carrier system. A description of this type of core material and a statement of the results obtained by its use in the telephone plant will form the subject of an engineering paper to be published at an early date.

As has been indicated above, the attenuation of the filter outside of its efficient transmission band, determines the necessary frequency separation between the side bands of adjacent channels and therefore to a large degree also the number of channels which may be operated in a given frequency range. For example, if channel A is operating through the filter shown in Fig. 14, then the frequency band of channel B must be so chosen in the frequency range that the attenuation of the filter in channel A for currents of the frequencies of channel B is at least as great as some value fixed by the cross-talk requirements imposed on the system.

The attenuation outside of the transmission band is practically independent of the resistance of the coils and the dissipation in the condensers, but is determined almost wholly by the arrangement and values of the reactances employed in a section and by the number of sections. Numerous special arrangements have been devised for controlling the form of the attenuation curve and for giving to the filter an impedance best suited to the circuit with which it is connected. It has been found practicable to design filters which permit of operating with an interval of about 1000 cycles between adjacent telephone channels; that is, 3000 cycles between adjacent carrier frequencies.

In addition to separating the various carrier channels from each other it is found convenient from an operating standpoint to separate within the toll offices the carrier frequencies as a group from the frequencies used for ordinary telephony and telegraphy. For this purpose the portion of the line which is used in common is connected with the carrier apparatus through a "high-pass" filter, which transmits all frequencies above a predetermined value (in this case above about 3000 cycles), and suppresses all frequencies below this value (in this case below 3000 cycles). Similarly connection is made with the ordinary telephone and telegraph circuits through a "low-pass" filter, which in this instance passes frequencies

below 3000 cycles and suppresses those above. This combination of carrier line filters, sometimes called a "high-frequency composite set," is shown in Fig. 15, together with the attenuation curves of the two filters. Referring to this figure, it will be seen that currents in the multiplex line divide between the low-pass and high-pass filters shown at the top of the figure. The division is determined at any particular frequency by the relative input impedances of these two branches. Accordingly, the high-pass filter is designed to offer a high input impedance to currents of ordinary telephone frequency, and to have an impedance equal to that of the line for currents within the carrier frequency range. Correspondingly,

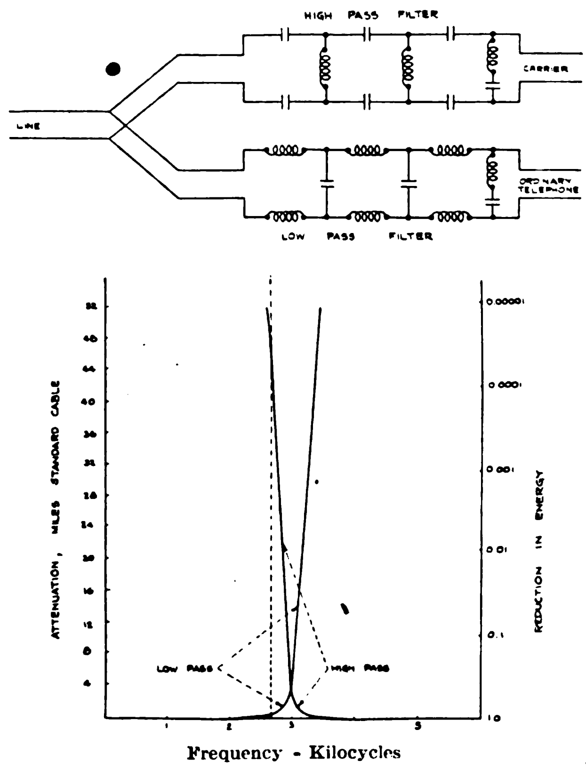

Fig. 15

the low-pass filter is designed to offer a high input impedance to currents of the carrier frequency range and to have an impedance equal to that of the line for currents of ordinary voice frequencies. The attenuation of the high-pass filter is small for carrier frequencies and large for voice frequencies, while the reverse is true for the low-pass filter. Referring to the attenuation curves, which show, as indicated, the attenuation for both the high-pass and the low-pass filters, it is interesting to note how sharp a discrimination is obtained even for frequencies very close to the cut-off points of these filters. For instance, if we select a frequency of 2700 which happens to fall near the upper limit of the normal voice range, it is seen from an inspection of these curves that currents of this frequency are attenuated by about one mile of standard cable when passing through the low-pass filter, but are attenuated by about forty-five miles of standard cable when passing through the high-pass filter. Likewise, a frequency of 3200 near the lower limit of the carrier range is attenuated by less than one mile when passing through the high-pass filter, but is attenuated by about forty-five miles when passing through the low-pass filter. These differences in attenuation correspond roughly to a ratio of energies greater than ten thousand to one.

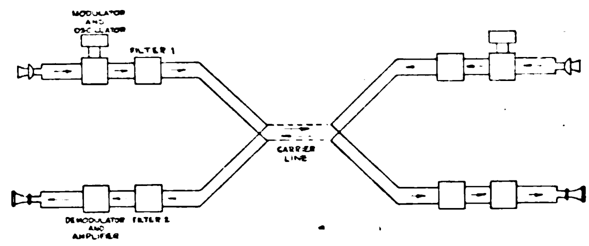
Fig. 16

The location of these line filters in a carrier system is indicated in Fig. 13. A low-pass filter is also used in the output circuit of the demodulator to prevent currents of frequencies higher than the essential voice range from being transmitted to the subscriber.

Arrangements for Two-way Transmission. Thus far the discussion has been limited to transmission in one direction. Provision must be made, however, for associating these one-way channels with the connecting telephone lines so as to permit two-way conversation. In many aspects the problem resembles that encountered in adapting a one-way amplifying element to a two-way talking circuit by means of a telephone repeater. The similarity of the two problems consists not only in the fact that the carrier channel and the

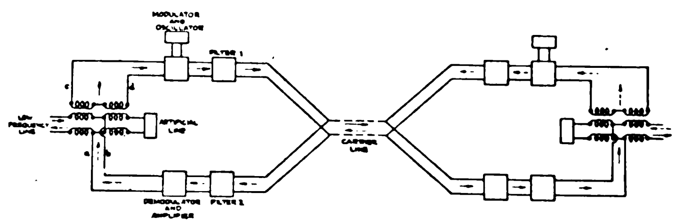
Fig. 17

repeater element are both unilateral or one-way arrangements, but also that both involve amplification, and therefore the same possibilities of "singing" are present in the case of the carrier as in the case of the repeater. The experience, which was gained in the development and engineering of telephone repeaters, has proved of very great value in connection with the development of carrier current systems. For details of the various circuit arrangements, and for a discussion of the fundamentals of the repeater problem, reference may be made to the paper on telephone repeaters mentioned above.[21]

21. Gherardi and Jewett, loc. cit.

In Fig. 16 there is shown schematically an elementary form of two-way carrier telephone circuit. Filters are included in the transmitting and receiving branches, as they are necessary in those branches for multiplex operation. This circuit is entirely operative between two fixed telephone stations. If the same frequency is used for transmitting in both directions, there will obviously be an excess of sidetone in the receiver circuits. It is plain that such a type of circuit has very limited commercial application, and it is shown here merely as a starting point for building up the more generally applicable types.

As in general it is desirable to be able to connect any desired telephone trunk or toll line to the section of line equipped for operation by the carrier current method, it is necessary to adopt for connecting these lines together a circuit of the type which has been studied for many years by telephone engineers, first in connection with subscriber sets, and second in connection with repeater circuits.

Fig. 17 shows schematically one such arrangement. At either terminal of the carrier frequency line, the sending and receiving branches, instead of terminating in a transmitter and receiver, terminate in what are, in effect, conjugate branches of an alternating-current bridge. If the impedance of the artificial line exactly simulates the impedance of the voice frequency line looking outward from the carrier terminal, an electromotive force applied between the points *a* and *b* does not cause any current to flow in the branch *c*-*d* of the carrier current circuit. This represents a condition of zero coupling between the input and output circuits of the carrier system; hence persistent oscillations, *i.e.* singing, cannot be set up. If, however, the balancing network does not accurately simulate the low-frequency line, either of two types of singing may occur. In the circuit arrangement in Fig. 17, if the same frequency is used for transmission in both directions, the type of singing most likely to occur would be local singing at either terminal. This occurs for the reason that in general the amount of energy applied to the two terminals *c* and *d* is largely amplified in the course of passing through the circuit—modulator, filter 1, filter 2, demodulator and amplifier. If the unbalance in the bridge circuit is such that the fraction of this energy which is fed back to the points *c* and *d* is as large as that originally supplied, singing occurs. To avoid this type of singing different carrier frequencies may be chosen for transmission in the two directions. If this is done, local singing cannot be set up, for the reason that filter 2 acts as a block to the return of the output current on itself. End to end singing as distinguished from local singing may, however, occur provided the over-all transmission loss of the line and the terminal apparatus is made less than zero, and provided that there is sufficient unbalance between the artificial lines and the low-frequency lines at both ends. By "transmission loss of less than zero" is meant that the attenuation of the carrier line is more than compensated for by amplification introduced either at the terminal stations or at intermediate repeater stations. However, the accuracy of line balance necessary to prevent end to end singing with carrier circuits such as we have used is very much less than would be required to prevent local singing if the same frequency were used for transmission in both directions. It is interesting to note that in both of these types of singing the sustained oscillations in different portions of the circuit are of different frequencies. Those in the portions used for transmission at voice frequency have some value lying in the voice frequency range. Those in the portions used for transmission at carrier frequencies differ from the carrier frequency associated with that particular channel by the frequency of the oscillations in the low-frequency circuit.

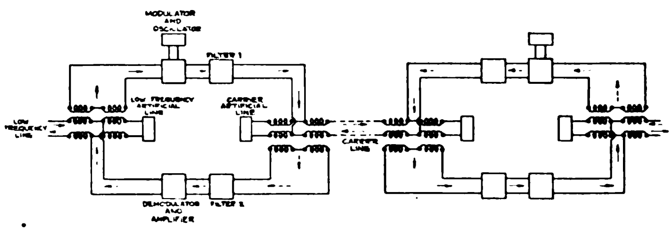

FIG. 18

Whereas, with the circuit shown in Fig. 17, local singing is prevented by the use of different carrier frequencies in the two directions, it is possible to prevent this type of singing without resorting to different frequencies, with the attendant reduction in number of channels, by the use of the arrangement shown in Fig. 18. In this arrangement the energy from the output of the modulator is prevented from reaching the input of its associated demodulator by placing the two in conjugate relation in an alternating-current bridge circuit, of which the carrier frequency line forms one arm, and a balancing network, designed to simulate the line impedance, the other arm.

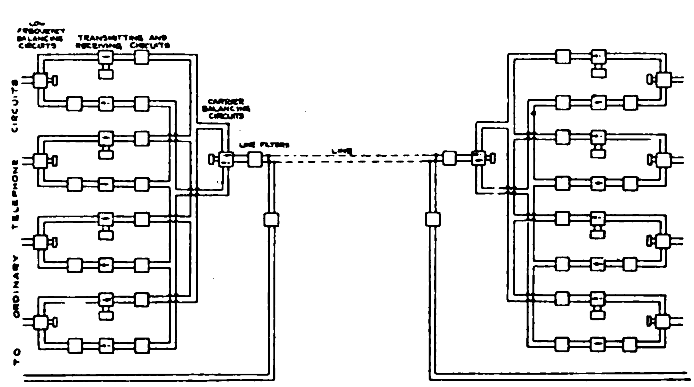

FIG. 19

Both the arrangements shown in Fig. 17 and that

shown in Fig. 18 have been successfully employed for two-way carrier current transmission.

We have already discussed quite fully the selective characteristics of filters and their relation to one-way multiplex operation, and have, in the preceding paragraphs of the present section, pointed out the fundamental principles of two-way operation. In Fig. 19 is shown schematically an arrangement for two-way multiplex operation capable of giving four two-way carrier conversations in addition to the normal telephone facilities. It will be noted that, in this multiplex system, the basic two-way transmission system of Fig. 18 is employed. A similar two-way multiplex system could be built up employing the basic two-way transmission system shown in Fig. 17.

Carrier Suppression. One of the systems which has been developed, particularly for use on long high-grade circuits, involves certain fundamental principles in addition to those already discussed. It will be recalled, that as stated, the proper operation of the demodulator requires that the side-band currents, by

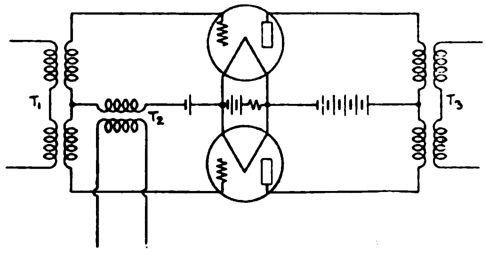

Fig. 20

which are transmitted the characteristics of the speech, be accompanied by a relatively large amount of unmodulated current of carrier frequency. When this carrier current is transmitted from the modulator, it is evident that only a relatively small part of the line current is actually used in conveying the characteristic variations of the voice current. If, therefore, this carrier current is supplied to the demodulator from a local source instead of over the line from the sending station, the amount of line current which it is necessary to transmit per channel is very materially reduced, for then only the relatively small side bands are transmitted. Curve E, Fig. 11, shows the wave form with the carrier suppressed when both side bands are present; and Curve F, Fig. 11, shows the wave form with the carrier suppressed when only one side band is present. In the application of this method, means must be provided for eliminating the carrier current at the sending end and for supplying it to the demodulator from a local source at the receiving end.

Elimination of the carrier frequency at the sending end can be accomplished by what is known as a "balanced modulator," a schematic circuit of which is shown in Fig. 20. In this arrangement two tubes are connected in a manner somewhat similar to the "push-pull" repeater circuit which is described later. The voice frequency potential is applied differentially to the grids of the two tubes by the transformer T_1. The carrier potential is applied through the transformer T_2 to the common portion of the input circuit in such a manner that the carrier frequency potentials of the two grids with respect to the filament are at any instant the same. The resultant carrier frequency currents in the plate circuits of the two tubes are then equal, and the fluxes which they set up in the core of the differential transformer T_3 are equal and opposite; hence no voltage of the frequency of the unmodulated carrier is induced in the output circuit. By a more detailed analysis it can be shown that the side-band currents resulting from the interaction of the carrier and speech-frequency currents are not balanced out but are reproduced in the output circuit. It should be noted that under these conditions, high-frequency current appears in the output circuit only when low-frequency telephone currents are being applied to the input circuit of the modulator.

Harmonic Generator. In order to insure that the carrier current applied to the demodulator in the above system, employing suppressed carrier, is of exactly the same frequency as that used for modulation at the sending end, an arrangement has been devised whereby both of these frequencies are derived from the same source. For this purpose at one terminal of the system a vacuum-tube oscillator generates a frequency somewhat above the voice range—say 5000 cycles. Current of this frequency is applied to the input of another vacuum tube in such a way as to overload it. This "harmonic generator," as it has been termed, is so arranged that the current in its output circuit has a distorted wave-form containing prominent components whose frequencies are exact multiples of the applied frequency. The various harmonics of the base frequency (in this case 10,000, 15,000, 20,000 cycles, etc.) are separated by suitably designed selective circuits and led into individual circuits where they are amplified and made available for use as carrier currents, each in connection with a different channel. At the same time, current of the base frequency from the controlling oscillator, in this case 5000 cycles, is amplified and transmitted over the line to the other terminal. Here it is separated out by a filter, amplified and applied to a second harmonic generator, which produces the same series of carrier frequencies as does the harmonic generator at the controlling station already referred to. These regenerated harmonics may not only be used for demodulating the transmissions received from the controlling terminal, but may also be used in connection with balanced modulators which send in the reverse direction. The demodulators at the controlling station, are supplied with carrier current from the harmonic generator at that terminal.

The suppressed carrier system, besides employing smaller line currents, has two other important advan-

tages. One is the absence of audible beat notes resulting from interaction in the demodulating circuits between the carrier frequency normally present and others which may be present through cross-talk or lack of perfect balance. Where all of the carrier frequencies are generated separately, these combination frequencies may in certain cases give rise to disturbing tones within the voice range. With the harmonic arrangement, on the other hand, the only possible frequencies are differences of the base frequency itself and its harmonics, all of which are above the normal voice range, and accordingly are suppressed by the low-pass filter in the output circuit of the demodulator. As a matter of fact, this harmonic arrangement is practically essential where the same frequency range is used for both directions.

The second advantage arises from the fact that variations in the attenuation of the line, due to weather changes or other causes, have less effect on the transmission equivalent of the system where the carrier frequency itself is not transmitted. This will be clear when it is recalled that the magnitude of the voice current in the output of the demodulator is proportional to the product of the amplitudes of the carrier and side band currents. If, therefore, the change in line attenuation is such as to increase or decrease the side band current by a given ratio, the carrier current when transmitted will in general also be changed in the same ratio, and the resulting voice current will be changed by the square of this ratio. In the suppressed carrier system, on the other hand, while the side band is changed as before, the carrier is increased or decreased—not by the change in attenuation which occurs at the carrier frequency—but by the changes, in general much smaller, which occur at the base frequency, so that the voice current is less affected in this case.

(*To be continued*)

Some Phases of Railroad Telegraph and Telephone Engineering

BY STANLEY RHOADS

Telegraph & Telephone Engineer, New York Central Lines

(*Continued from page* 232 *of JOURNAL for March,* 1921)

Welded Iron Wire Joints

Another step in the improvement of iron wire for telephone circuits is due to oxyacetylene welding of the joints. This has been successfully done on the No. 8 B. W. G. iron wires of the Hocking Valley, Zanesville & Western, and Cleveland, Cincinnati, Chicago and St. Louis Railroads. The resistance of a welded joint is 95 per cent of that of an unspliced wire, whereas the usual soldered joint is 112 per cent of the unspliced wire. Many apparently soldered joints are really not soldered and are about 200 times the resistance of the same length of unspliced wire. The joints are painted with red lead after welding. The work is not excessive in cost and the result is a considerable reduction in resistance and is of a permanent nature. A recent job of welding on the C. C. C. and St. L. Ry., cut the transmission equivalent of the circuit almost in half.

Composite Ringer

The operation of a type B composite ringer was investigated with the oscillograph with the results shown in Fig. 14. Oscillogram No. 193 is the simultaneous record of the outgoing signals when the home station operator rings. Trace No. 1 is the 16-cycle motor-generator ringing current from the operator's keys. Trace No. 3 is the 133-cycle current as produced by the interrupter and delivered to the line, and is flowing to a station 150 miles away over a No. 9 A. W. G. copper phantom circuit, composited.

Oscillogram No. 192 is the record of an incoming signal from the distant office. Trace No. 2 is the wave

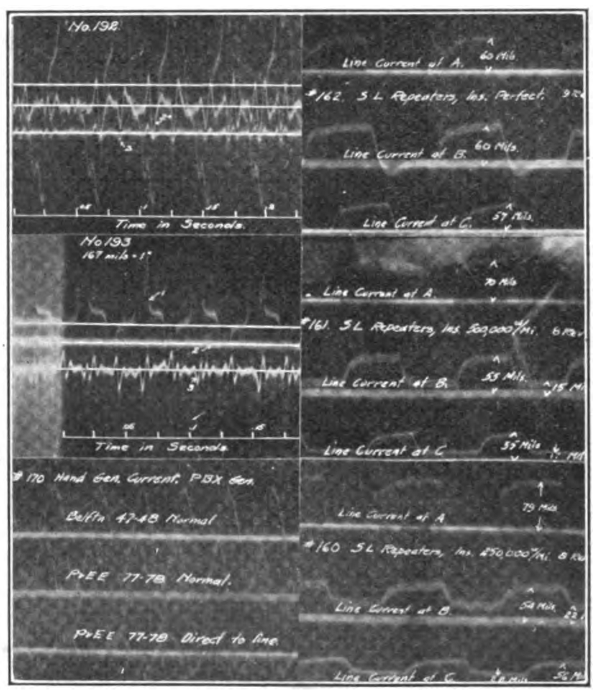

Fig. 14

at a point in series with the high frequency relay and is the deflection calibrated at 50 milliamperes per inch, whereas the No. 1 and No. 3 are 167 milliamperes per

inch as in No. 193. The waves do not resemble sine waves to any noticeable extent but are distorted more like transformer magnetizing current. Oscillogram No. 170 is shown for comparison with hand generator ringing current and presents three separate exposures; the top one on a No. 8 B. W. G. iron wire way-station message selector telephone line, Indianapolis to Bellefontaine; and the middle one is the same generator ringing on a similar circuit, Indianapolis to Springfield, Ohio, through a No. 47-A repeating coil; and the lower trace is on the same line without the repeating coil. The calibration of the oscillograph vibrator elements was not alike in these three exposures.

selector telephone circuits was registered automatically on Veeder counters. The records for several telephone dispatching circuits is given in Table III.

The number of calls per day is interesting. It runs as high as 1223, which is as high as on any existing dispatching circuit, because it is an exceptionally busy line and one man could not do much more on one circuit.

The record of transmitter energy consumption is given in Table IV for several offices in the C. C. C. & St. L. general office building, Indianapolis. The above record gives data for the total of all transmitters in the general office building, and a four-volt, 25-ampere-

TABLE III

Energy Consumption Data on Various Selector Telephone Circuits.

C. C. C. & St. L. Ry.

Division Name	Circuit No.	Length of Line, Miles	Kind of Wire C-Copper I-Iron	Size of Wire No. 9 AWG No. 8 BWG	Type of Selectors 4G5 = 5000, 4G16 = 1600, 4G7 = 7000	No. of Selectors	Voltage at Generator	Milliamperes at Generator	During 24 hours: A. C. Motor kw. Hours	No. of Calls	No. of Trains	Ampere hours: Call Box Battery	Main Line Battery	Selector Main Line Battery	Selector Local Battery	Main Line Volt Ampere Hours
Cincinnati	31–2	78.7	C	9	4 G 5	32	160	200	3.6	1223	85	0.716	0.245		0.154	39.2
Columbus	"	45.1	"	9	4 D 16	20	"	145		"	43				0.152	
Delaware	"	49.9	"	9	4 G 7	12	"	72		"	19				0.206	
Above three are operated as one circuit																
Cincinnati	73–4	78.7	I	8	" 5	43	330	218	5.1	403		0.275	0.496		0.145	163.5
Columbus	71–2	45.1	"	8	" 5	21	85	82		173		0.079	0 0199		0.27	16.9
Delaware	71–2	49.9	"	8	" 7	13	78	64		319		0.304	0.38	0.27	0.11	29.7
Sandusky	31–2	130.7	C	9	" 7	33	107	105	3.5	539	83		0.3	0.07	0.208	32.1
Sandusky	75–6	34.0	I	8	" 5	13	170	138	3.7	163		0.379			0.55	
Chicago East	31–2	109.6	C	9	" 16	32	210	250			45	0.095	0.085			17.8
Chicago West	31–2	139.8	"	9	102-C	35	180	260			35	0.162	0.094			16.9
Peoria & Eastern	31–2	211.5	"	9	102-F	55	300	285	13.3		22	0.076	0.130			39.0
Springfield	31–2	140.1	"	9	102-C	34	140	150			15	0.13	0.086			12.0
Chicago East	51–2	109.6	"	9	4 G 16	34	240	250				0.101	0.045			10.8

Energy Consumption

Several tests have been made to determine the energy consumption of different circuits used in railroad service, particularly those which use primary battery, in order to compare costs of different types of battery. In general, the ampere-hour energy consumption was recorded by copper voltameters and in some cases by watt-hour meters, for periods of 24 hours, of days that were considered average. The number of calls on

TABLE IV

Energy Consumption Data of Transmitters—for 24 Hours.
Gen. Telg. Office, Indianapolis, C. C. C. & St. L. Ry.

Transmitter tested	Battery supply	Ampere hours
Chi. Div. Dis. East	8 B. S.C.O. Cells	1.162
" " " West	8 " " "	1.499
" " Chf. Disp	4 " " "	0.069
" " Msg. Opr	4 " " "	0.1365
" " Car Dist	4 " " "	0.0199
P. & E. Disp. East	8 " " "	1.765
" " " West	8 " " "	0.845
" " Supt.-Car Dist	8 " " "	0.0659
Supt. Terminals	5 Dry "	0.0265
Wire Chief	10 " "	0.0522
Short line	3 " "	0.00269
		5.55 total

hour battery was set up which has since supplied all these transmitters.

The shunt field current of a motor of a dispatcher's selector-circuit motor-generator was found to be 0.3 ampere, which is eight ampere-hours per day, sufficient to charge the 24-ampere-hour battery on the transmitters. The storage battery was placed on continuous charge in this shunt field circuit without either affecting the other detrimentally.

It is quite general practise to feed all local battery transmitters around a railroad general office building from a four-volt or six-volt storage battery of small capacity, placed on continuous charge from the 110-volt d-c. lighting circuit or other available d-c. supply. No cross-talk results, if sufficient copper is used in the busbars from the battery to the distribution point and if the plates of the cells are not too far apart. This continuous charge method requires less supervision than a daily charge method.

It was noted in making the transmitter current tests that new transmitters of a given type use more current than old ones, in some cases twice as much. This is in conflict with the general belief that old trans-

mitters are "packed" and consequently use more current. An explanation for the higher resistance of old transmitters is that the granules lose their many sharp edges and become more nearly round with fewer points of contact with other granules, which increases the resistance of the carbon as a whole with resultant smaller current flow.

Table V shows the record for a selector calling-key battery which was provided for by a twelve-volt, six-ampere-hour storage battery connected in the shunt field of a small motor of a dispatching-circuit motor-generator set.

A test was made on a 48-volt storage battery supplying a Western Electric Co. No. 10, private branch exchange with 45 stations at Beech Grove Shops. The board is operated from 8:00 a. m. to 5:00 p. m., except Sunday, and has six trunks to the main railroad exchange at Indianapolis. The record showed 5.27 ampere-hours per day. The charging rate was based on this at five amperes for eight hours, once per week, with suitable overcharge periods.

TABLE V

Energy Consumption Data of Call Boxes for 24 Hours, Gen'l. Telegraph Office, Indianapolis, C. C. C. & St. L. Ry.

Chi. Div. Disp. East	6 Dry Cells	0.0957
" " " West	7 " "	0.1625
" " Msg. Oper	8 " "	0.101
P. & E. Dis. East	8 " "	0.1326
" " " West	8 " "	0.0761
		0.567 total

A four-ohm sounder used 1.25 ampere-hours in a 24-hour period on two gravity cells. The record for the Chicago Division message operator shows (Table IV), 0.1365 ampere-hour in 24 hours. This transmitter is in almost constant use, sending and receiving messages for the Division Superintendent's office. Therefore, it can be said to fairly represent the average busy local battery telephone on a railroad, consuming more energy than the average way station or block tower. On this record it could be predicted that a 300-ampere-hour set of batteries of equivalent voltage would last 2200 days—or six years. Actually, they would not last quite so long, but are known to last three years and more in this service. At an initial cost for four cells of $8.94 and renewal cost of $5.72 for consumable elements, the cost is less than $2.00 per year, based on three-year life of renewals. Dry cells, three per set, would last about three months and cost about $4.50 per year at 28 cents each. In addition to saving in cost, the caustic soda cells give desirable reliability and require less labor expense. It is standard practise to connect the transmitters of all telephones at any station, and all the telephone selector bells to the same set of caustic soda battery.

Unit Type Power Switchboards

The rapid and uncertain growth of dispatching and message telephone circuits has made it difficult to plan motor-generator sets for battery supply and keep a neat layout of power plant. The C. C. C. & St. L. Railway experienced this trouble and the unit type was adopted. This is shown in Fig. 15. Morse battery supply also has been installed on this plan at Springfield, Ohio, to fit in with the units for the selector lines.

The plan provides one square foot of power panel with the motor and generator line switches, line fuses for both generator and motor, field rheostat, circuit breaker and voltmeter for each machine and in close relation to it. The generator circuits are taken through a jack panel at the left end of the bench, where any machine can be put on any circuit. This type of power installation saves space and puts the control apparatus in close proximity to the motor-generator.

Dry cells have been supplanted by motor-generators and sodium-phosphate-aluminum-iron chemical rectifiers for selector telephone circuits, to a great extent. The motor-generators in the first installations had shunt-wound generators with the inherent characteristic of drop off in voltage with increase of load which was undesirable on selector telephone lines. The load on a dispatcher's circuit consists of series of twenty or thirty short impulses, seldom more than 1500 series per day, which is practically no-load from a power standpoint. The efficiency of a machine therefore, is of less importance than good voltage regulation. The compound generator has been used in all recent installations on the New York Central Lines, separately excited if the motor power supply is direct current.

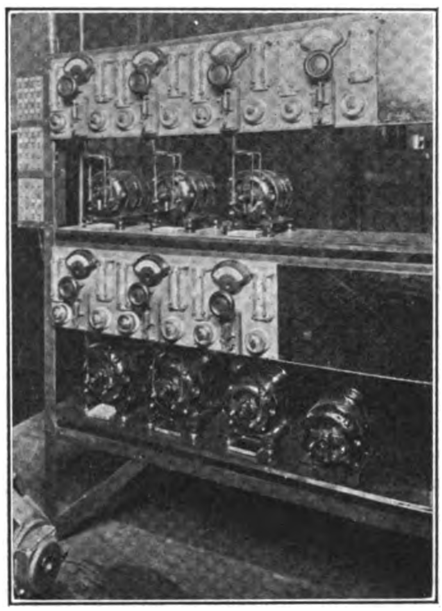

Fig. 15—Unit Type Power Switchboards for Selector Telephone Circuits

Alternating current has been found better suited for the motor supply than direct current, because of

its better regulation. The direct-current power from railroad shops has poor regulation, due to the arc welders, etc., in the shops.

Quick starting motors have been used in some installations, and while fairly successful, are not preferred to the constantly running sets, because of excessive wear of the commutator, due to heavy starting current. Four-bearing motor generators have been found to give better results than two-bearing type. Ring oilers are better than wicks.

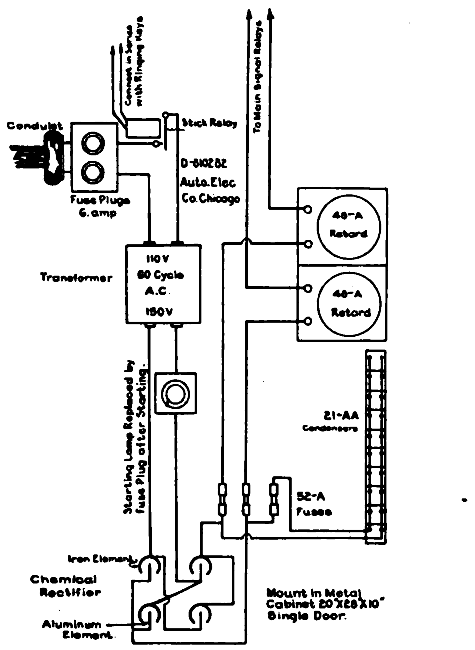

Fig. 16—Wiring of Chemical Rectifier for Selector Telephone Circuits

Chemical Rectifier

The use of the sodium-phosphate chemical rectifier is being extended. The first few sets were purchased but later installations are made up completely by the railroad installers. Four old type sal-ammoniac battery jars are used, containing a solution of commercial sodium phosphate, made up of one pound dissolved equally between the four jars of water, in which is suspended a semi-circular strip of iron separated about one inch from an aluminum strip. Fig. 16 shows the wiring of such an outfit for a dispatching circuit. The condensers and retard coils eliminate the hum of the alternating-current source on the telephone line. The stick relay normally disconnects the rectifier from the a-c. supply between calls on the dispatching line. Fig. 17 shows characteristic curves of such a set. The unmarked curve is the efficiency.

"Single" Morse Current Waves

Perhaps the best known phenomenon to the telegraph fraternity is the sharp snap of the relay when the "single" Morse circuit is closed and opened at the home station, as compared with the comparatively sluggish impulse received in the same relay when a distant station is sending. The comparison is evident in Fig. 18 in oscillogram No. 165 which has two separately made exposures. Trace No. 1 was made at Indianapolis on a single No. 8 B. W. G. iron way wire to Mattoon, Ill., 128 miles long, with forty 120-ohm main line sounder instruments cut in on it with Indianapolis sending. Trace No. 2 is at the same place but with Mattoon sending. The peak of trace No. 1 is the line charging current that gives the snap to the home relay but does not get to the distant station, due to its establishing the electrostatic flux of the line. The No. 163 indicates the current in a

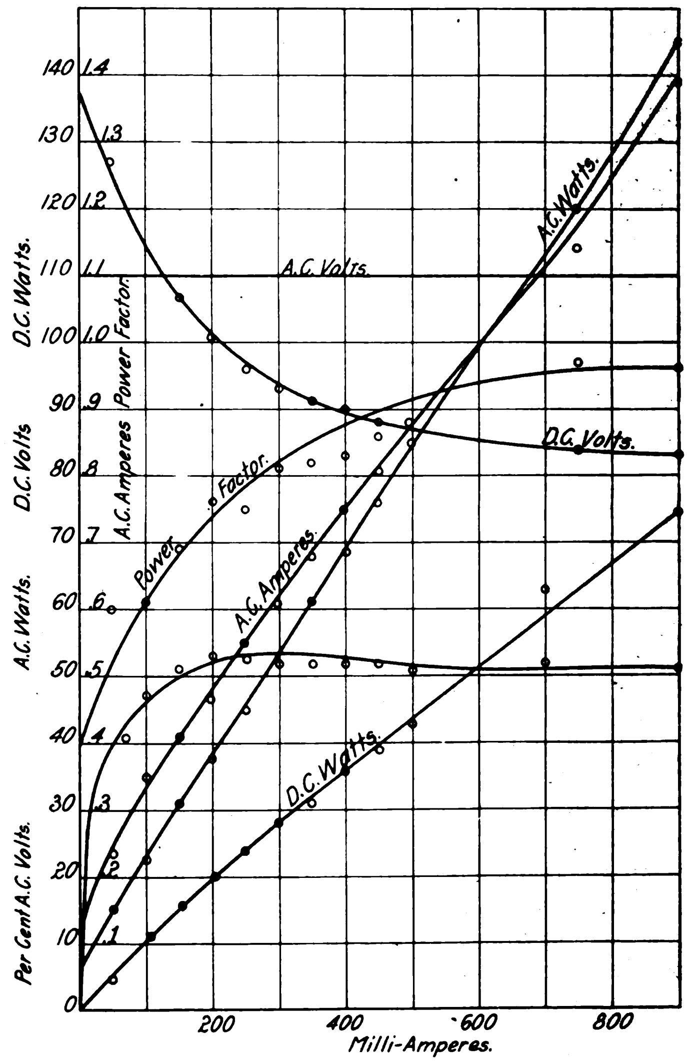

Fig. 17—Characteristic Curves of Chemical Rectifier

block simplex circuit composed of two No. 8 B. W. G. iron wires 140 miles long, Indianapolis to Bellefontaine, Ohio, with 45 Morse relays, 35-ohm, with 79 No. 47-A repeating coils as simplex coils. The upper trace is with Bellefontaine sending and the lower with Indianapolis. The middle trace is on a No. 8 B. W. G.

iron simplexed selector telephone line between the same points.

Telegraph Repeaters

Some tests on telegraph repeaters were made upon an artificial line, shown in Fig. 19, which represented two 150-mile lines with telegraph repeaters connecting them. The line leakage was adjustable to either of three conditions, *viz.*, perfect insulation, ½ megohm per mile and ¼ megohm per mile, by means of switches. Shunt-locking repeaters were used. Oscillogram No. 162 of Fig. 14 records the current simultaneously at three points, with a condition of perfect insulation. The line current at A is the current of the extreme end of one line with the station at that point sending the signals. The current at B is the resultant wave at the other end of the sending line. The line current at C is the resultant current wave that reached the far end of the second line, after being repeated by the station B. This record, compared with No. 165, indicates very close approximation to a real line, as the wave-shape at A is very much like the wave-shape in the upper trace of No. 165, which is under somewhat similar conditions; that is, it is the sending station on a line with several instruments and perfect insulation. The wave-shape at B is much like the wave in the lower trace of No. 165, and both are the received waves at the distant end of a line.

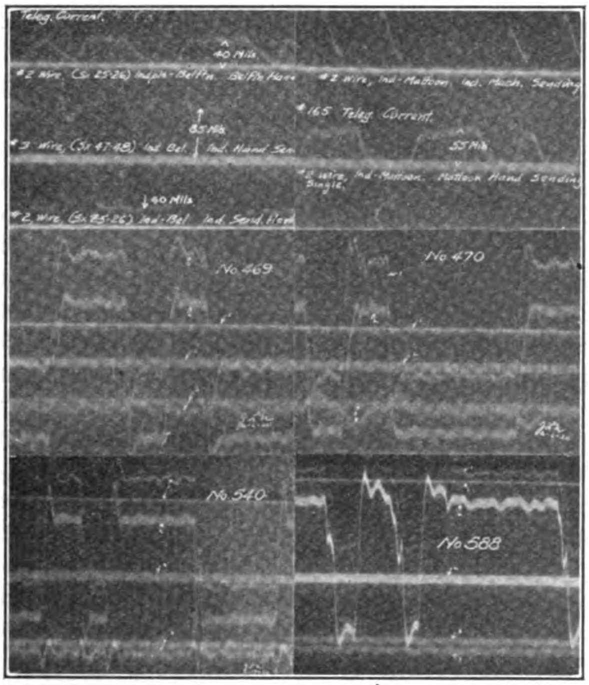

Fig. 18

In No. 162 the time lag between the sending impulse at A and the received impulse at C is considerable. The records represent about one-tenth second to the inch, which indicates that it takes nearly one-twentieth second from the closure of key at A, until the impulse begins at C. The impulses were made with an impulse machine of clockwork with a governor for speed adjustment, and are uniformly 6 per second.

Oscillogram No. 161 is the record at the same points as No. 162, but with line leakage reducing the insulation to one-half megohm per mile. This value of insulation is as low as it is desirable to permit for satisfactory single Morse operation. In this record it is seen that the wave does not become zero at B, when the key opens at A, because the line battery at B causes leakage current to flow. The repeater adjustment is the same in this record as in No. 162. It was lined up for good Morse signals in No. 162 and was not further adjusted. Oscillogram No. 160 is

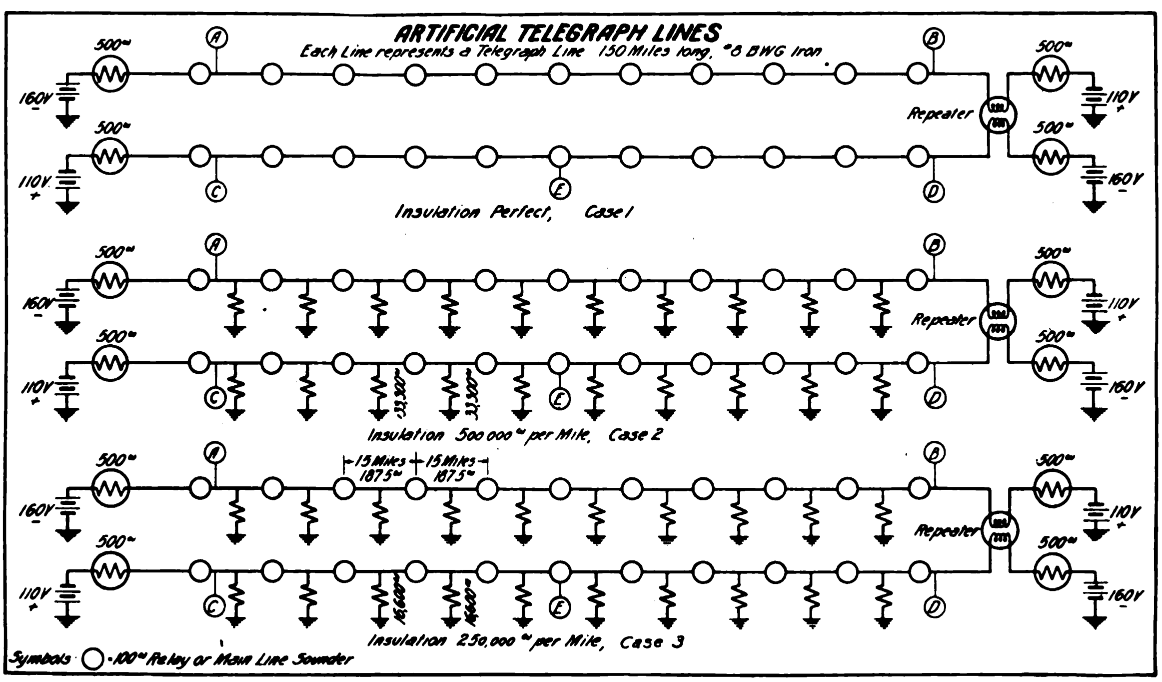

Fig. 19—Artificial Telegraph Lines

the record with the insulation still further reduced to one-quarter megohm per mile, and shows that only little more than half the current was cut off at B by opening the key at A. The tests showed that the signals received at C were unreliable but could be made readable by slight readjustment of the relay at C and without any readjustment of the repeaters at B, which indicates the wide margin of the repeaters. This very low value of insulation is not often found on single wires even in the worst weather if the line is well maintained, but is more frequent on the simplexes with their two wires, which nearly halves the insulation resistance value.

It is not practicable to assume from the above tests that these repeaters will not require readjustment with changing weather conditions. It is seldom that a set of repeaters is adjusted to its very best with perfect line insulation conditions, but it will require attention with change of weather sooner than if perfectly adjusted for good insulation conditions. Table VI gives the current readings at various points in the two artificial lines as actually measured, for different key positions and the three conditions of line insulation resistance.

TABLE VI

Milliammeter location	Current—milliamperes		
	Insulation perfect	½ Megohm per mile	¼ Megohm per mile
A, line closed	60	70	78
A, open at B	0	32	52
B, line closed	60	55	54
B, open at A	0	15	22
C, line closed	57	55	56
C, open at D	0	17	28
D, line closed	57	63	70
D, open at C	0	30	50
E, line closed	57	55	50
E, open at D	0	8	10
E, open at C	0	15	20

Line Insulation

Low insulation apparently is due more to broken and chipped glass insulators than to smoked ones. A perfect insulator measured 40 megohms with a 500-volt megger meter and a similar one measured 10 to 15 megohms with a piece of the outer petticoat of about two inches width knocked off, with the same condition of rain in both tests. An insulator so badly shattered that the tie-wire was holding it together, measured 1 megohm in a drenching rain and when thoroughly water-logged. A mechanically perfect insulator but one very badly crusted by smoke, measured about 40 megohms, after a hard rain, which is about the same value a clean insulator shows. The crust deposited by smoke seems to have high resistance. The megger tests were made on actual lines from line wire to ground after cutting off the line wire about a foot each side of the tie wire. It was found that the resistance from line to pin nearly always equalled the value from line to ground, when the pole and cross-arm were wet. It is important to keep chipped and broken insulators off a line on which the working margin demands good insulation. This is especially important on simplexes, because of the reduced insulation of the two wires in parallel.

Leakage from Wire to Wire

Few references are available relating to the effect of line leakage of one wire on a pole line to a paralleling wire on an adjacent pin. This point came up in a study of a proposal to string a common return wire on an inter-calling selector telephone circuit to take the place of a ground return, installed on the Indianapolis Belt Railroad, semi-circling the city. The telephone selector ground return was affected badly by the city street railway return current, also leakage in wet weather made the ground return so unreliable that some other plan was necessary. The third wire was proposed but it was known that the insulation of the two wires to ground was very low in wet weather and it was feared that the leakage to the third wire would make the system inoperative at such times.

The experiences of telegraph and telephone men were obtained and the general opinion was that the leakage from the two line wires as a simplex to the third wire as a common return would be negligible. The effect was actually found to be less than one-third of the leakage current that existed with the ground return. Assuming that the wires of the telephone pair in wet weather had an insulation resistance of one megohm per mile each, which in parallel was ½ megohm to ground, the third wire with one megohm has its insulation resistance in series with the ½ megohm of the pair, which would make the result theoretically 1½ megohms or three times what it was between the pair and ground.

This type of inter-calling system is limited to very short lines of perhaps a maximum of ten miles, due to the variable operating current of the simplex connection resulting from insulation leakage. The permissible length is 100 per cent greater with a return wire than with a ground return. Circuits 100 to 150 miles have not proved successful.

The leakage from one wire of the pair to the other under ordinary conditions on selector telephone lines has no noticeable effect upon selector operation. The net resistance is the sum of the resistance of each, and the effective voltage to cause leakage current falls from the value of the main battery, usually 200 to 300 volts at one end, to less than 50 volts at the distant end, on most types of selectors, and the total leakage current causes very slight additional voltage drop on the circuits and no apparent effect on the selector operation.

The leakage from one telegraph wire to another can be detected by means of a voltmeter by opening one wire at the distant end, inserting the voltmeter at the home end between the line and ground, and applying voltage to the paralleling wire. The value of the leak

age is so slight that it is seldom observed in the Morse relays of the circuits if worked as single Morse, or on the polar relays if worked as a duplex. The electrostatic induction from paralleling wires, apparently, is noticed more than the leakage.

It has been stated that, in the past, the insulation of railroad circuits was too variable and low to permit of successful loading of open wire lines. Judging from recent tests of insulation, it is now believed to be feasible to load the railroad long-distance lines, which are limited to through service. It would, probably, not be successful on phantoms made up of selector telephone lines.

Single Morse

Both theory and practise indicate that 30 to 35-ohm relays or main line sounders are more desirable than 100 to 150-ohm, for iron wire way-station telegraph circuits, whether single wire or simplex. The actual result has been demonstrated a number of times on the New York Central Lines by changing all the instruments from 100 or 150 ohms to 30 and 35 ohms with marked improvement in the service.

The operating current of telegraph relays, for satisfactory service on railroad way wires, should be something close to the following:

> 30 to 35-ohm relays or main line sounders, 65 milliamperes, closed circuit, to 40 milliamperes on open circuit. The difference between these values gives a margin of 25 milliamperes.
>
> 100 to 150-ohm relays or main line sounders, 40 milliamperes closed circuit, to 25 milliamperes on open circuit. This is a margin of 15 milliamperes.

Formulas for calculating telegraph line current values for the conditions of closed circuit and distant key open, are as follows:

1. For the condition of keys closed:

$$I = \frac{E}{R + \sqrt{\frac{r}{g}}\,\tanh \frac{L}{2}\,\sqrt{r\,g}}$$

2. For the condition of distant key open:

$$I = \frac{E}{R + \sqrt{\frac{r}{g}}\,\coth L\,\sqrt{r\,g}}$$

E is voltage at one terminal, R is terminal resistance of one terminal, r is average line resistance including relays, g is the leakage conductance, mhos per mile, and L is the length of line in miles.

Table VII gives the results of calculations made for the purpose of comparing the current values of single wires and simplexes with 150-ohm relays and 35-ohm relays; with 500,000 and 250,000-ohm line insulation resistance per mile, on No. 8 B. W. G. iron wire.

The two No. 8 B. W. G. iron wires in parallel, in a simplex, have the resistance of the No. 47-A repeating coils added. There are two coils at each intermediate station and one at each end. The intermediate station coils add 21 ohms per station, and the terminals 10.5 ohms, making the average resistance of the circuit 10.4 ohms per mile, which is not a great reduction below the value of a single No. 8 B. W. G. iron wire. The simplex has double the leakage current of a single wire, assuming the same insulation resistance values for both wires. On these simplexes better insulation is desirable than can be permitted on single wires. Comparison of computations Nos. 4 and 6 of the table shows that the margin of a simplex with 500,000-ohm insulation resistance per mile is about the same as a single wire with half that insulation resistance.

TABLE VII

Computed current values, telegraph line 150 miles long with 30 relays comparison of single wire and simplex for three conditions of insulation.

Computation Number	Resistance of relays ohms	Resistance of insulation ohms per mile. per wire	Current—milliamperes: Line closed (a)	Line open distant end (b)	Margin i. e. difference between (a) & (b)	Margin required for satisfactory operation	Dry weather current perfect insulation
	Single No. 8 B. W. G. iron, 12.4 ohms per mile.						
1	150	500,000	52.3	28.9	23.4	15	46.
2	35	500,000	96.5	35.2	61.3	25	91.2
3	150	250,000	58.3	43.3	15.0	15	46.
4	35	250,000	101.5	57.1	44.4	25	91.2
Simplex, No. 8 B.W.G. iron, 10.4 ohms per mile, including simplex coils							
5	150	500,000	60.2	44.1	16.1	15	48.1
6	35	500,000	108.1	58.2	39.9	25	100.
7	150	250,000	70.6	62.3	8.3	15	48.1
8	35	250,000	110	86	24.	25	100.

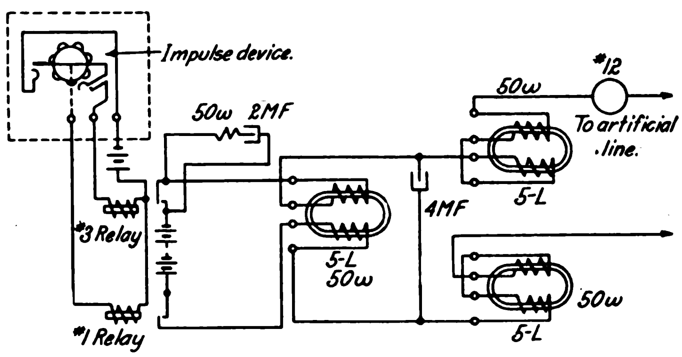

Fig. 20—Signaling Set for Selector Telephone Circuits with 3-5L Coils

The table shows that the 35-ohm relays have better margin than 150-ohm relays under the same conditions of insulation. Comparison of computations Nos. 3 and 4 shows, that the margin is at the limiting value with 150-ohm relays and 250,000-ohm insulation, whereas

the 35-ohm relay margin at 44.4 milliamperes is still. satisfactory. Comparison of computations Nos. 7 and 8 shows similar results on a simplex circuit.

It is found in practise that an entire circuit seldom has a uniform value of insulation resistance in wet weather, because of the variable rainfall rate. It is generally clearing at one end of a division when raining hardest at the other end.

Telephone Selector Current and Voltage Waves

In Fig. 20 retard coils and condenser are indicated in a telephone selector signaling circuit, which are for the purpose of modifying the voltage wave that is impressed on the line so that it will not give listeners on the telephones a disagreeable sound shock. Some investigations were made on an artificial line of Fig. 22 through the signaling equipment of Fig. 20 with the result shown in oscillogram No. 5. The oscillogram No. 127 of Fig. 21 shows the voltage on the battery side of the coils as trace No. S and the simultaneous result on the line side as trace No. 1. The line current is trace No. 2. This shows that the line voltage and current are practically in phase. Considerable delay in the progress of the wave on the line is indicated both at the make and break of the circuit. The condensers in the middle of the retard coils act as a storage battery and assist to prevent the sudden collapse of line voltage when the relay opens. They also cause high initial counter e. m. f. in the coil between them and the battery when the relay closes, thus rounding off and delaying the growth of the line wave. The resultant current wave on an actual line is shown in No. 101. This was taken on a 110-mile dispatching No. 9 A. W. G. copper wire circuit, Indianapolis to Cincinnati, equipped with 32 Sandwich type 4-G selectors, with a main battery of 220 volts. In No. 101, the capacity of the telephone condensers added to that of the line causes a decided oscillatory action at the end of impulses. This is aided by the capacity and retardation in the wave modifying set.

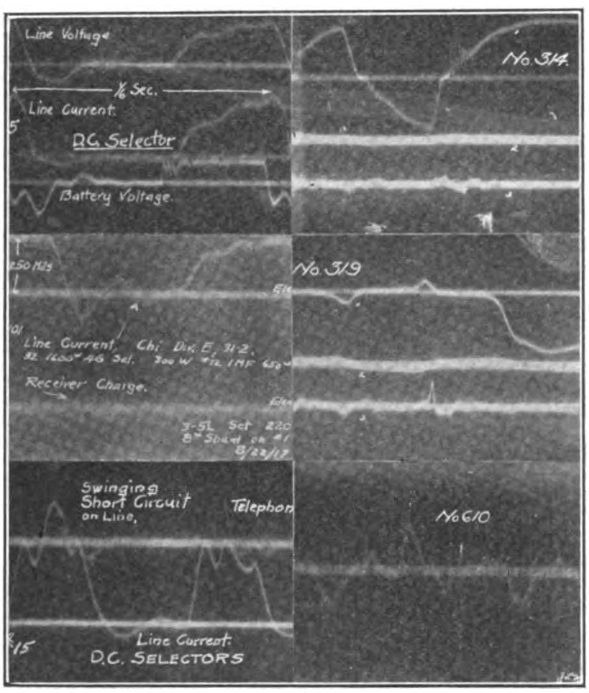

Fig. 21

The cause of the vicious sound in the receiver which occurs due to a swinging short circuit on the line while selector impulses are being sent, is shown in oscillogram No. 15. The upper trace is the telephone condenser wave and the lower is the line current. The short circuit is removed at about the middle of the wave with sudden increase in line voltage with resultant rapid charging of the condenser in the telephone receiver circuit which causes the disagreeable sound shock.

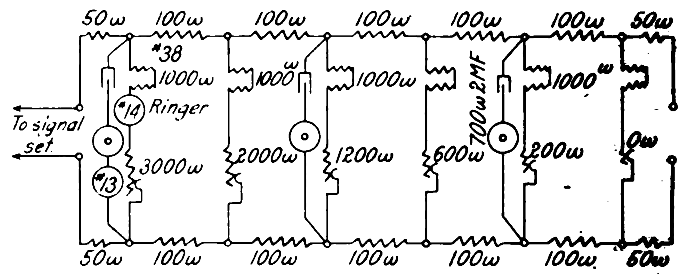

Fig. 22—Artificial Selector Telephone Circuit

The condenser signal sending set of Fig. 23 was recorded in No. 50 and No. 51 of Fig. 24 sending impulses into this artificial selector line, first with 125 volts main charging battery and then with 325 volts. This type of sending circuit is in use to a limited extent on some railroads. The brevity of the line current wave is the outstanding feature of these two records.

The above mentioned Sandwich selectors on the Indianapolis-Cincinnati dispatcher's telephone line were replaced by 32 Western Electric Co. alternating-current selectors, type 60-A, with wiring as shown in Fig. 11; and oscillogram No. 380 shows the current in the battery side of the repeating coils as trace No. 1 and in the line as trace No. 2. This circuit has the condensers removed from the selectors and lumped in the battery side of the repeating coil. The impulses as registered in the line at the sending station on the Indianapolis-Kankakee dispatching telephone circuit, a 140-mile No. 9 A. W. G. copper circuit of 35 No. 60-A alternating-current selectors, is shown in No. 590, in which trace is the line current. These selectors are operated with a condenser in series with each selector and with

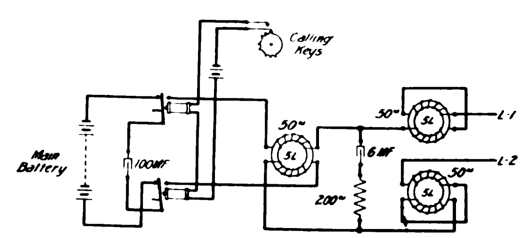

Fig. 23—Condenser Type Signaling Set for Selector Telephone Circuits

the main battery applied directly to the line. It will be noted that the first impulse, which is the closure of the No. 122-E W relay, is but half the amplitude

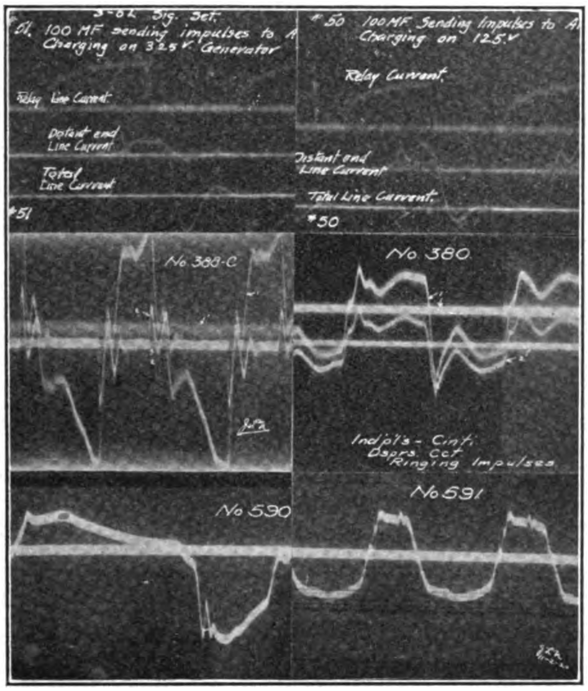

FIG. 24

of the following impulses. Oscillogram No. 591 is the Kankakee circuit line current with the repeating coil signaling set of the Cincinnati circuit sending impulses. The resulting impulses are only half the amplitude of the impulses of the regular signaling set, shown in No. 590. This method is now being experimented with. It is the more desirable plan because with condensers in the bridging selectors the wire chief can make accurate Varley loop Wheatstone bridge measurements for trouble. If the direct battery ringing set of the Kankakee line is put on the Cincinnati circuit which has the condensers removed from the selectors, the result is as shown in No. 388-C, trace No. 1, which is the line current.

Oscillograms No. 319 and No. 314 of Fig. 21 show the comparative impedance of a No. 47-A repeating coil and a D-12984 coil, which is used for the signal sending repeating coil for alternating-current selectors and also as a simplex coil for the "distant" end of such circuits. Trace No. 1 of No. 314 is the current in the No. 47-A coil at the Indianapolis end of an Indianapolis-Bellefontaine No. 9 A. W. G. copper alternating-current selector line 140 miles long, equipped with 45 a-c. selectors not operated through a repeating coil at the sending end, but with the battery applied direct to line at Bellefontaine.

Trace No. 2 is the current through the selector which had two microfarads capacity in series with it. Trace No. 3 is in the phantom telephone branch on this circuit. In No. 319, trace No. 1 is the current through a D-12984 coil. The lobes of this wave on the short impulses are much smaller than on No. 314, indicating much less effect on the line current, while the continuous impulse is somewhat the same shape in both.

No. 610 shows the current through the D-12984

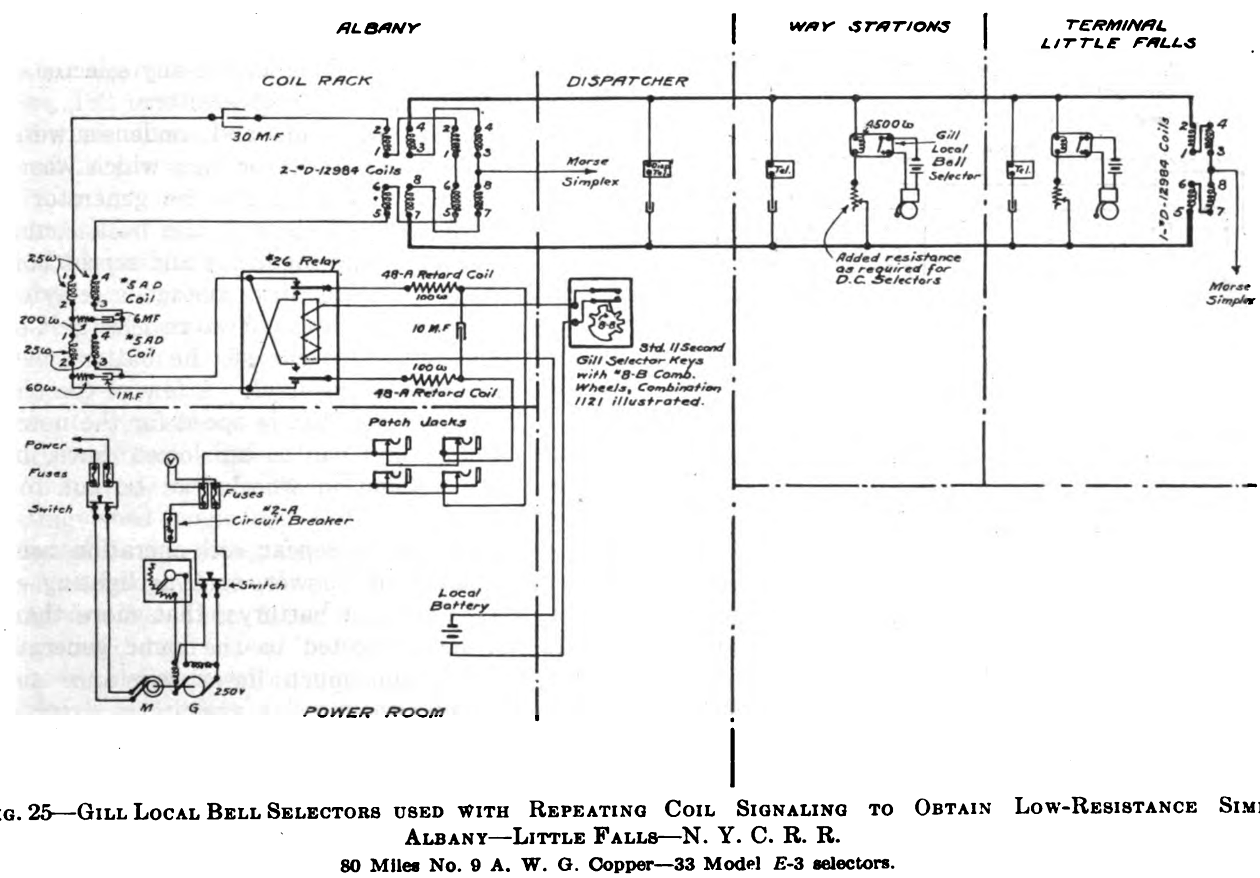

FIG. 25—GILL LOCAL BELL SELECTORS USED WITH REPEATING COIL SIGNALING TO OBTAIN LOW-RESISTANCE SIMPLEX—ALBANY—LITTLE FALLS—N. Y. C. R. R.
80 Miles No. 9 A. W. G. Copper—33 Model *E*-3 selectors.

coil at Indianapolis after the condensers from the selectors had been lumped in a repeating coil type of signal sending set of Fig. 11, at Bellefontaine.

Gill Selectors as A-C. with Low Resistance Simplex

The repeating coil method of operation is applicable to types of impulse selectors which do not require main line battery for ringing the selector bells. The Gill local battery selector, of which a great many are in use, is in this class and is successfully operated through the D-12984 repeating coil, as shown in Fig. 25. The circuit on which this was first used is the Albany-Little Falls dispatching telephone line, which was the first telephone train dispatching circuit in this country; the first one to have selectors, which were the Gill telegraph type, used on a third wire; the first to have selectors on the same wires as the dispatching circuit, which was the series Gill type with selectors in the line at one station in one wire and in the other wire at the next station, alternating first in one wire and then in the other, and operated by simplex current. These series selectors were later replaced by the first "bridging" Gill selectors which are still there and are now converted to "alternating-current" operation, so-called, and are the first circuit of Gill selectors to be so operated.

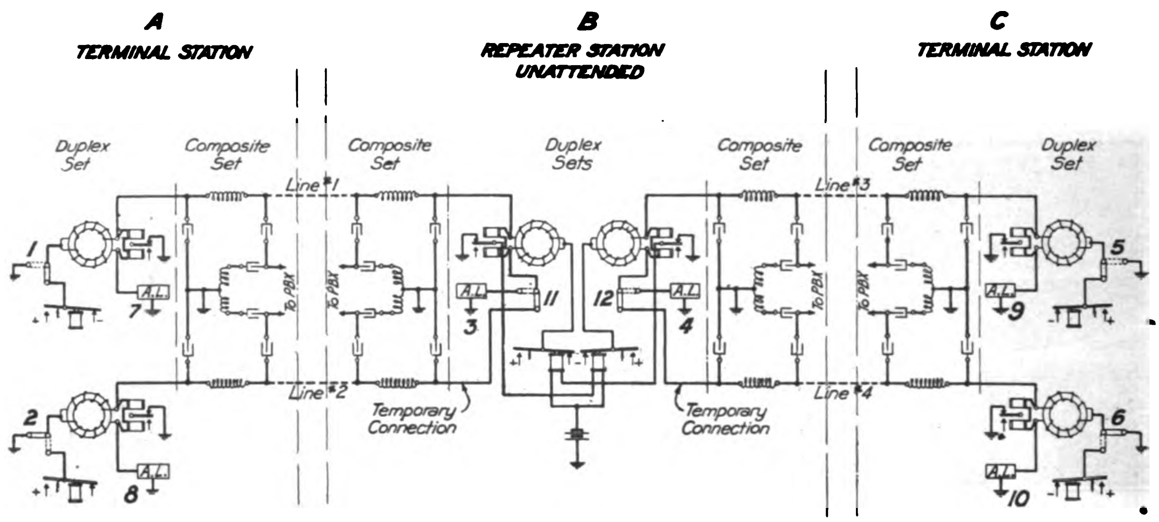

Fig. 26—Unattended Self-Balancing Duplex Applied at Repeater Station

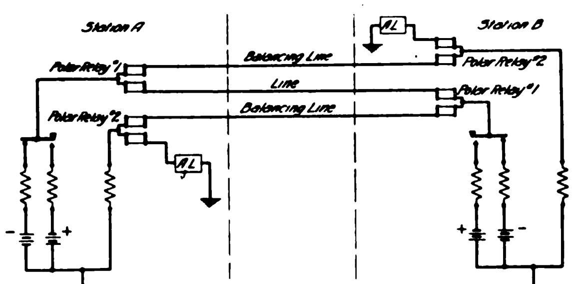

Fig. 27—Theory of a Duplex Circuit Showing Three Wires

The No. 26 relay replaces the ordinary single-contact telegraph relays formerly used; the condensers and repeating coils were installed and new No. 8-B combination wheels were made for the dispatcher's calling keys, and designed so that one impulse is sent when the key contact makes and another when it breaks; otherwise, no change was made in the circuit. The added resistance in series with the selectors was not altered and the current distribution seems to be satisfactory. The circuit is No. 9 A. W. G. copper, 80 miles long with 33 selectors. About one microfarad per selector is enough capacity in the repeating coil circuit to operate the selectors properly. Slightly less main battery is required than before the change was made. The repeating coils reduced the simplex resistance 1000 ohms. It is believed that the method will be found successful on almost any selector circuit now equipped with this type of selector.

The No. 48-A retard coils and condenser were necessary to reduce the generator hum which was heard on the line without them, due to the generator being continuously connected through the back contact of the No. 26 relay, to the condenser and repeat coil. If a key is designed with a third contact, a relay can be inserted, as is used with the Western Electric Co. No. 60-A apparatus case to cut off the battery between operations of the calling keys. A few of the old Gill keys were slightly too fast in speed for the new combination wheels and had to be slowed down, but in future, the combination wheels can be cut to take care of this.

The advantages of repeat coil operation are that grounded sources of power, such as lighting circuit can be used for main battery; that more than one circuit can be connected to the same generator or power supply; and much lower resistance simplex telegraph circuits result.

Polar Duplex and Quadruplex Operation

The standard polar duplex of the Western Union Telegraph Co. is in use on the N. Y. C. Lines, on a

total of 36 circuits and on 9903 miles of circuit. The preferred type is convertible from bridging to differential. The differential is used on composited wires in which the retardation of the Morse leg is sufficient to round off the outgoing wave, and prevent induction trouble. The bridging set is used on simplexes and single wires.

The standard quadruplex is used to a limited extent. As with the duplex, the preferred type is convertible from bridging to differential, and the differential should be limited to use on composited wires.

The action of bridging duplexes and quadruplexes as installed in accordance with the Western Union Telegraph Company's specifications, has been studied to learn their characteristics and better their performance and speed of service, so that such circuits in railroad service can be relied upon to give full output as "double" duplexes and "four-cornered" quadruplexes.

A polar duplex or quadruplex is approximately a three-wire circuit, usually consisting of an actual line and two artificial lines. Actual lines may be substituted for artificial lines as indicated at station B of Fig. 26. Fig. 27 indicates the three wires of a duplex using actual lines in place of artificial lines to balance both No. 1 polar relays. As indicated in Fig. 27 actual or dummy duplex sets are needed at both points designated as No. 2 P. R. With these dummy sets, artificial lines are needed to enable the distant station to get the best balance practicable. Carrying the idea further, it would be possible to use actual lines in place of these artificial lines, also placing dummy sets at the distant ends. In turn, these dummy sets would require balancing lines. Thus, theoretically, the number of balancing lines could be multiplied infinitely. In practise, the balance is found to be practicable with but two balancing lines, and no dummy balancing sets are ordinarily used with artificial line boxes. Hence, the term "approximate" three-wire circuit seems to be a correct designation for a duplex or quadruplex. The artificial line can never exactly balance the real line because there is always one more wire between "home" battery and distant ground in the line side than in the artificial line side, as is readily seen in Fig. 27.

(*To be continued*)

SCHOLARSHIP AND ENGINEERING EMINENCE

A close correspondence between good scholarship in college and eminence in engineering is shown in an investigation made under the auspices of the American Association of Collegiate Registrars by Prof. Raymond Walters of Lehigh University, who presents a report in the current issue of *School and Society*.

It was found that, of 392 distinguished engineers graduated at 75 technical schools, colleges and universities, 182 or 46.4 per cent stood in the highest fifth of their classes scholastically upon graduation, 109 or 27.8 per cent stood in the second highest fifth, 72 or 18.3 per cent in the middle fifth, 14 or 3.6 per cent in the next lowest fifth, and 15 or 3.8 per cent in the lowest fifth.

Figures for a group of 189 alumni of five Eastern engineering schools were somewhat different in the upper classes, the second highest scholastic fifth having the largest percentage. In all groupings of the eminent engineers there were less than 4 per cent in each of the two lowest scholastic fifths.

Of 730 names on the Registrars' Association list of distinguished engineers, practically 80 per cent were found to be collegiate graduates, 16 per cent men of secondary school education and practical training, and less than 5 per cent men who started in college but did not finish.

The arbitrary basis of eminence in this study of a professional group was taken to be the holding of office, membership in important committees and service as representatives of the four national engineering societies of civil, mining, mechanical and electrical engineers, for five years, 1915-1919.

EXPERIMENTAL RADIO MARKET NEWS SERVICE

A daily market report prepared by the U. S. Bureau of Markets is now being sent by radio from the laboratory of the Bureau of Standards at 5 p. m. each day except Sundays and holidays. This report is known as the Daily Radio Marketgram. It is about 500 words long and gives prices and market conditions of fruit and vegetables, grain, dairy products, hay, feed, and seeds, livestock and meats of the principal markets in the nation. Any radio operator within a 200 mile radius of Washington can receive the report. It is transmitted on a wave length of 400 meters at a rate of 15 words per minute. A 2-kw., 500-cycle transmitting set is being used with a non-synchronous rotary spark gap. The report is opened by the general call signal to all stations (Q S T) and the call signal of the Bureau of Standards (W W V).

This service was started as an experiment to determine whether the distribution of market news by radio could be conducted in a satisfactory manner. All radio operators and other persons interested in receiving this information are requested to lend assistance in making the experiments successful. Suggestions for its improvement will be welcomed; It is probable that this experimental service will be extended by the transmission of market news by radio from several other stations including some in the mid-western states. In case this extension involves the substitution of some other station for the Bureau of Standards (W W V) notice to this effect will be broadcasted by radio on several nights from the Bureau's station before its use is discontinued.

Circle Diagram of Polyphase Induction Motors

BY J. K. KOSTKO

Wagner Electric Mfg. Co.

In submitting this article the writer wishes to disclaim any intention of making a contribution to the theory of a subject so thoroughly studied as the circle diagram of polyphase induction motors. But while the theory of the circle diagram may be considered as a closed chapter, its practical application, as a method of determining the characteristics of motors from test data, has not kept pace with the theory; at least, all constructions known to the writer are either not simple enough for practical use, or are based on assumptions which hold good only within rather vaguely defined limits; in particular, there is no simple and accurate method applicable to small and fractional horse power motors for which the approximate diagram is entirely inadequate.

The method given in the article is applicable to all cases, but has been primarily developed and used in connection with small motors, its characteristic feature being that the smaller the motor, the easier the construction of the diagram. It is thought that in view of the enormous development of the small motor industry this feature may be of sufficient interest to justify an addition to the literature of the circle diagram.

THE circle diagram of the induction motor is usually based either on the approximate equivalent circuit of Fig. 1 or on the exact circuit of Fig. 2. The object of this article is to make a brief study of the circuit of Fig. 3, intermediate between Figs. 1 and 2,

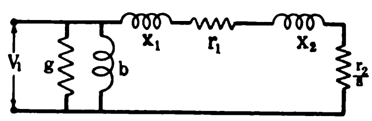

FIG. 1

and physically equivalent to a motor without core loss connected in multiple with a core loss circuit g; it will be shown that this circuit combines the advantages of Figs. 1 and 2; its circle diagram is practically as accurate as the exact locus of Fig. 2[1], and in point of simplicity of construction from test data it comes

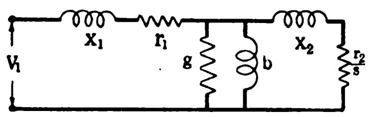

FIG. 2

fairly close to that of Fig. 1, especially for small motors, *i. e.*, precisely where the approximate diagram of Fig. 1 is not applicable.

For the study of the current locus of Fig. 3 it is convenient to retain the transformer analogy of the motor by replacing the susceptance b by a transformer T,

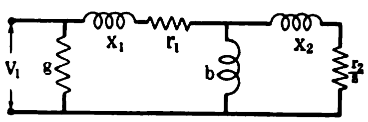

FIG. 3

Fig. 4, without leakage and of 1 to 1 ratio; each winding of this transformer will have a reactance $X = 1/b$.

Let $O\,I$, Fig. 5, be the current I_1' in the branch $x_1 - r_1 - X$; the applied voltage V_1' is the sum of the ohmic drop $r_1 I_1' = O\,R'$, the counter e. m. f. of leakage reactance $x_1 I_1' = R'\,S'$, the counter e. m. f. of primary reactance of T, $XI'_1 = S'\,C'$, and the e. m. f. $X\,I_2' = C'\,E'$ induced in the primary of T by the secondary current I_2'. $E'\,O$ represents the applied voltage V_1'. I_2' is induced in a circuit of resistance r_2/s and reactance $X + x_2$ by the e. m. f. $X\,I_1' = S'\,C'$ due to the primary current, and the phase relation of e. m. fs.

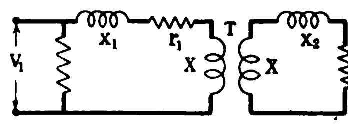

FIG. 4

$S'\,C'$ and $C'\,E'$ results from the vector diagram of the secondary circuit $S'\,C'\,E'\,U'\,S'$ in which $S'\,C' = X\,I_1'$, $S'\,U' = r_2/s \times I_2'$, $U'\,C' = (X + x_2)\,I_2'$, and $E'\,C' = X\,I_2'$.

If the branch $x_1 - r_1 - X$ is supplied with constant current I_1', $S'\,C' = X\,I_1'$ remains constant, and the

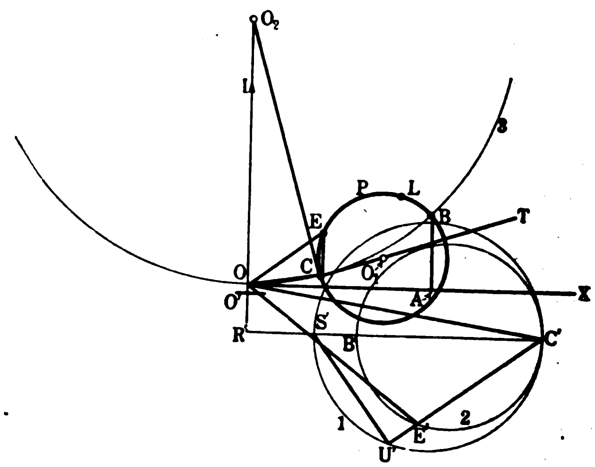

FIG. 5

point U' moves on a circle 1 described on $S'\,C'$ as diameter. Since $C'\,E' = C'\,U' \times \dfrac{X}{X + x_2} = C'\,U'$ $\times$ constant, the point E' moves on a circle 2 described on $B'\,C' = S'\,C' \times \dfrac{X}{X + x_2}$ as diameter; this circle is the

1. See Note 1 in appendix.

locus of applied voltage at constant current. At C', $(X + x_2) I_2' = 0$, *i. e.*, $I_2' = 0$; and, since $r_2/s \times I_2' = S' C' \neq 0$, the slip must be zero; C' is the no-load point. At B' the point U' coincides with S' and

$$\frac{r_2}{s} \times I_2' = S' U' = 0; \text{ but } I_2' = \frac{B' C'}{X} \neq 0,$$

therefore $s = \infty$. At B' and C' the resultant e. m. f. $S' E'$ is at right angles to the current $O I$, *i. e.*, at these points the torque is zero.

From locus 2 of applied voltage at constant current I_1' the current locus at constant voltage V_1 is derived by inversion with O as center and $V_1 I_1'$ as constant of inversion, followed by substitution for the inverse figure of its image with respect to $O Y$[2]; this transforms the circle 2 into the final circular locus P. This locus of the motor branch $x_1 - r_1 - X$ will obviously become the locus of the entire circuit of Fig. 3 if the origin is moved to a point O' such that $O' O$ = current in the core loss branch g.

Let B and C on the circle P correspond to B' and C' on the circle 2. Since the circle 2 is normal at B' and C' to the line $R' C'$, the circle P is normal at B and C to the inverse of $R' C'$; the latter is a circle 3 of diameter

$$\text{equal to } \frac{I_1' V_1}{O R'} = \frac{V_1}{r_1}, \text{ having its center } O_2 \text{ on } O I.$$

This geometrical relation shows that *the center of O_1 of the locus P lies on the tangent $C T$ to the circle 3, i. e., on the perpendicular $C T$ to the segment $C O_2 = V_1/2r_1$ passing through the zero-torque point C.*

Construction of the Circle Diagram from Test Data

The required tests are: (1) Primary resistance r_1[3], (2) No-load test, (3) Locked test. Due to the friction torque the no-load point is slightly above the true zero-torque point C. This test point can be used in a preliminary diagram; if the friction torque is known, the zero-torque point can be approximately determined from this diagram and used for the construction of the final locus; but this refinement is seldom, if ever, necessary; usually the no-load point can be considered as the zero-torque point C.[4]

In Fig. 6 let $O' Y$ be the direction of the applied voltage and L and C the locked and the no-load points. The current locus passes through C and L, and its center is found, as explained above, by the following rule: *on $O' Y$ locate a point O_2 such that*

$$C O_2 = \frac{V_1}{2 r_1};$$

the center O_1 of the locus P is the intersection of the perpendicular bisector of $C L$ with the perpendicular $C T$ to $C O_2$. The circle 3 cuts the locus at B, where $s = \infty$, and the axis $O' Y$ at O, which corresponds to the point O of Fig. 5, *i. e.* it is the origin of currents in the branch $x_1 - r_1 - X$; $O' O$ is the core loss component; $O J$ (with $C J \perp O Y$) covers the ohmic loss of the no-load current $O C$ in the branch $x_1 - r_1 - X$, *i. e.* $V_1 \times O J = r_1 \times O C^2$; this can also be seen from the geometrical relation

$$O C^2 = (\text{diam. of } 3) \times O J = \frac{V_1}{r_1} \times O J.$$

In small motors the resistance r_1 is relatively so great that the radius

$$\frac{V_1}{2 r_1}$$

of the circle 3 is not excessive, and the locus can be constructed with an ordinary compass. If

$$\frac{V_1}{2 r_1}$$

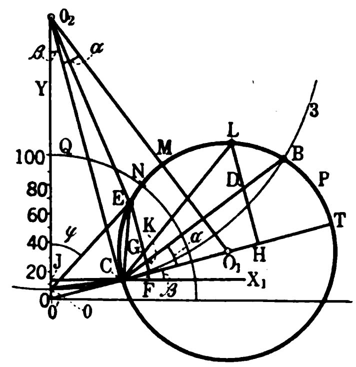

Fig. 6

becomes so great that the center of 3 lies at an inconveniently great distance, it is usually an indication that the angle of tilt of the locus is very small, and the approximate diagram of Fig. 1 is sufficiently accurate. In all cases the angle of tilt β and the points B and O can be found by calculation as follows:

Let I_0 be the no-load current and $J C$ its reactive component; since $O_2 C$ is perpendicular to $C T$, the angle $J O_2 C = \beta$, and the triangle $J O_2 C$ gives

$$\sin \beta = \frac{J C}{C O_2} = \frac{2 r_1 \times J C}{V_1} = \sim \frac{2 r_1 \times I_0}{V_1} \qquad (1)$$

The angle of tilt is thus nearly proportional to r_1; a good agreement between the locus and the brake test points can be expected only if r_1 is measured at the same temperature of the motor as during the brake test.

After the locus P has been constructed, its radius R can be measured and the point B ($s = \infty$) determined by calculating the angle $T C B = O_1 O_2 C = \alpha$ in the triangle $O_1 O_2 C$ which gives

2. See Arnold, Wechselstromtechnik, Vol. 1, 2nd ed., p. 70.

3. It is hardly necessary to add that the knowledge of the stator connection (star or delta) is not essential; if V_1 and r_1 are calculated as for the star connection, all conclusions will hold good, and the currents in the diagram will be line currents, regardless of the connection of the stator.

4. Note 4.

$$\tan \alpha = \frac{C\,O_1}{C\,O_2} = \frac{2 r_1 \times R}{V_1} \qquad (2)$$

The angle $O\,C\,J$ is measured by one-half of the arc $O\,C$ and is, therefore, equal to

$$\frac{\angle\, J\,O_2\,C}{2} = \frac{\beta}{2}\,;$$

i. e. the point O is the intersection of $O'\,Y$ with the bisector of the angle $T\,C\,X_1$; this point may be located by the eye.

Motor Constants and Performance Data Derived from the Diagram

Reactances x_1 and x_2. A circle diagram gives these elements only in combination; their sum x_s is found as follows: at B the slip

$$s = \infty, \frac{r_2}{s} = O,$$

and the motor branch of Fig. 3 is equivalent to the resistance r_1 in series with the reactance

$$x_1 + \frac{X\,x_2}{X + x_2} = \frac{x_1 + x_2 + x_1\,x_2\,/\,X}{1 + x_2\,/\,X}.$$

If $\varphi\infty$ is the angle of lag between the voltage and the current at B, then

$$\tan \varphi\,\infty = \frac{x_1 + x_2 + x_1\,x_2\,/\,X}{1 + x_2\,/\,X} \div r_1 = \frac{O\,A}{A\,B}$$

(Fig. 5); therefore

$$x_s = x_1 + x_2 = \sim r_1 \times \frac{O\,A}{A\,B} \qquad (3)$$

because the rejected terms are small relative to x_s. If greater accuracy is desired, this value of x_s may be corrected as shown below (form. 5).

Reactance $X = \frac{1}{b}$. At C the slip $s = O$, the secondary of T in Fig. 4 is open and the current in the branch $x_1 - r_1 - X$ is

$$O\,C = \frac{V_1}{\sqrt{r_1^2 + (X + x_1)^2}}$$

$$= \sim \frac{V_1}{X + x_1}\,;$$

hence

$$X = \frac{V_1}{O\,C} - x_1 \qquad (4)$$

Since x_1 is small relative to X, an appreciable error in the estimation of x_1 in this expression has a negligible influence on X; it can be assumed with a fair degree of accuracy that x_1 = 60 per cent of x_s with a wound rotor, and x_1 = 70 per cent of x_s with a squirrel-cage rotor.

This value of X can be used for correcting x_s as follows: let σ be the preliminary value of $\frac{x_s}{X}$ (analogous to the leakage coefficient of the approximate circle diagram); then

$$\frac{x_1 + x_2 + x_1\,x_2\,/\,X}{1 + x_2\,/\,X}$$

$$= x_s \left[\frac{1 + \sigma \times x_1/x_s \times x_2/x_s}{1 + \sigma \times x_2/x_s} \right] = r_1 \times \frac{O\,A}{A\,B}\,;$$

hence

$$x_s = r_1 \times \frac{O\,A}{A\,B} \times \frac{1}{M} \qquad (5)$$

where M is the expression in [ ]. With the preliminary value of σ M can be calculated for various values of

$$\frac{x_1}{x_s} \text{ and } \frac{x_2}{x_s} = 1 = \frac{x_1}{x_s}\,;$$

the corrected value of x_s is then found from (5). Fig. 7 gives M for the range of values of σ and $\frac{x_1}{x_s}$ occurring in practise; it shows that within normal limits of σ the correction is small and not much influenced by the arbitrary choice of $\frac{x_1}{x_s}$.

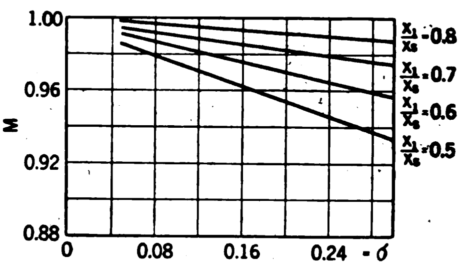

Fig. 7

Secondary Current I_2. In Fig. 5 the triangles $O\,C'\,E'$ and $O\,C\,E$ are similar because $\angle\, C'\,O\,E' = \angle\, C\,O\,E$ and $O\,E' \times O\,E$ = constant of inversion $= O\,C' \times O\,C$, *i. e.* $O\,E / O\,C = O\,C' / O\,E'$; therefore,

$$O\,E = C\,E \times \frac{O\,C'}{C'\,E'}\,;$$

but $O\,E = I_1$; $C'\,E' = X I_2'$;
$O\,C' = \sqrt{O\,R'^2 + R'\,C'^2} = I_1' \sqrt{r_1^2 + (X + x_1)^2}$, therefore,

$$I_1 = C\,E \times \frac{\sqrt{r_1^2 + (X + x_1)^2}}{X} \times \frac{I_1'}{I_2'}\,;$$

since

$$I_1 \times \frac{I_2'}{I_1'} = I_2,$$

this gives

$$\textit{Secondary current } I_2 = C\,E \times \frac{\sqrt{r_1^2 + (X + x_1)^2}}{X}$$

$$= \sim C\,E \times \frac{X + x_1}{X} \qquad (6)$$

i. e. the secondary current is proportional to the segment $C\,E$; the coefficient of proportionality

$$k = \frac{\sqrt{r_1^2 + (X + x_1)^2}}{X}$$

has a physical meaning: at no-load (open secondary in Fig. 4), the branch $x_1 - r_1 - X$ gives $V_1 = I_0 \sqrt{r_1^2 + (X + x_1)^2}$, and the *e. m. f.* due to the revolving field $= I_0 X$; therefore

$$\textit{Secondary current } I_2 = C\,E \times k = C\,E \times \frac{\text{applied voltage}}{\text{counter e. m. f. at no-load}} \qquad (6a)$$

Torque. In Fig. 6 let φ be the angle $E\,O\,O_2$; the input to the motor branch $x_1 - r_1 - X$ is $V_1 I_1 \cos \varphi$, and the input to the rotor-torque in synchronous watts is $V_1 I_1 \cos \varphi - r_1 I_1^2$; in the triangle $E\,O\,O_2$, $O\,O_2^2 - O_2 E^2 = 2 \times O\,O_2 \times O\,E \cos \varphi - O\,E^2$; but

$$O\,O_2 = \frac{V_1}{2\,r_1}\,; \; O\,E = I_1,$$

therefore,

$$O\,O_2^2 - O_2 E^2 = \frac{V_1 I_1 \cos \phi}{r_1} - I_1^2\,;$$

hence

$$\textit{Torque (per phase) in synchronous watts} = r_1 (O\,O_2^2 - O_2 E^2) \qquad (7)$$

Since

$$O\,O_2 = \frac{V_1}{2\,r_1} = \text{constant},$$

this shows that with a stator of given resistance the torque is the same at all points for which $O_2 E$ is constant, *i. e.* at all points of a circle concentric with the circle 3; the latter is the zero-torque circle. The torque is maximum where $O_2 E$ is minimum, at the intersection M of the locus with the perpendicular bisector of $C\,B$.

Let $E\,F$ be perpendicular to $C\,T$. In the triangle $O_2 E\,C$, $C\,O_2^2 - O_2 E^2 = 2\,C\,O_2 \times F\,E - C\,E^2$; if R is the radius of P, then $C\,E^2 = C\,F \times 2\,R$; but the similar triangles $O_2 C\,O_1$ and $C\,K\,F$ give $C\,F \times R = C\,O_2 \times F\,K$, therefore, $C\,E^2 = 2\,C\,O_2 \times F\,K$; substituting $C\,O_2^2 - O_2 E^2 = 2\,C\,O_2 \times F\,E - 2\,C\,O_2$

$$\times F\,K = 2\,C\,O_2 \times K\,E = \frac{V_1}{r_1} \times K\,E,$$

hence

$$r_1 (C\,O_2^2 - O_2 E^2) = \textit{Torque in synchronous watts} = V_1 \times K\,E \qquad (7a)$$

i. e. the segment $K\,E$ is equal to the component supplying the torque.

Secondary Output. The rotor copper loss is proportional to $C\,E^2$; but $C\,E^2 = C\,F \times 2\,R$, and $C\,F$ is proportional to $K\,G$ because the lines $C\,L$ and $C\,B$ are fixed; the rotor copper loss is, thus, proportional to $K\,G$, and the coefficient of proportionality is found by observing that at L the rotor copper loss is equal to the entire rotor input $V_1 \times D\,L$, which shows that the coefficient of proportionality is V_1, *i. e.* the segment $K\,G$ in amperes is equal to the component covering the rotor loss:

$$\textit{Secondary copper loss} = V_1 \times K\,G \qquad (8)$$

Equations (**7a**) and (**8**) give

$$\textit{Secondary output} = V_1 \times K\,E - V_1 \times K\,G = V_1 \times G\,E \qquad (9)$$

Thus, the components corresponding to the rotor input, output and loss can be taken from the diagram directly in amperes, *but the representative segments must be taken in the direction perpendicular to the diameter of the current locus, and not in the direction parallel to the direction of the applied voltage.*[5] The output is maximum at the intersection N of the locus with the perpendicular bisector of $C\,L$.

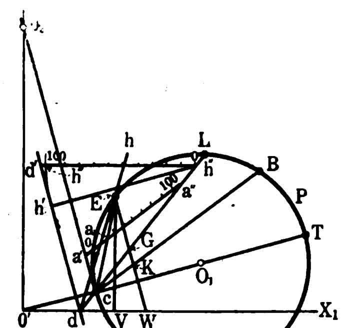

FIG. 8

At L the rotor copper loss $= r_2 \times (C\,L \times k)^2 = V_1 \times D\,L$; hence

$$\textit{Secondary resistance } r_2 = V_1 \times \frac{D\,L}{C\,L^2} \times \frac{1}{k^2} \qquad (10)$$

Determination of the Locked Point Corresponding to a given value of r_2. This problem arises, for instance, when it is desired to improve the performance by changing the size or material of rotor bars or end rings. Formula (**10**) gives: $D\,L/C\,L^2 = k^2 r_2/V_1$; in Fig. 6 $C\,L^2 = C\,T \times C\,H = 2\,R \times C\,H$, therefore, substituting, $D\,L/C\,H = 2\,R\,k^2 r_2/V_1$; but [formula (**2**)]

$$D\,H/C\,H = \tan \alpha = \frac{2\,r_1 R}{V_1}\,;$$

hence adding, $(D\,L + D\,H)/C\,H = L\,H/C\,H$

$$= \tan \angle\, L\,C\,H = \frac{2\,R}{V_1} \times (r_1 + k^2 r_2),$$

which determines the locked point L.

Slip. The slip is the ratio of the rotor copper loss to the total rotor input,

5. See Note 3.

$$s = \frac{K\,G}{K\,E}.$$

As $K\,G$ cannot be read accurately, it is preferable to write

$$\textit{Slip}\ s = \frac{D\,L}{K\,E} \times \frac{K\,G}{D\,L} = \frac{D\,L}{K\,E} \times \frac{C\,F}{C\,H}$$

$$= \frac{D\,L}{K\,E} \times \left(\frac{C\,E}{C\,L}\right)^2 \tag{11}$$

Graphical Determination of the Slip. In Fig. 8 draw $a'\,a''$ parallel to $C\,B$ at any convenient distance. The similar triangles $G\,K\,C$ and $C\,a'\,a''$ give (a) $K\,G/C\,K = C\,a'/a'\,a''$; the similar triangles $E\,K\,C$ and $C\,a'\,a$ give (b) $K\,E/C\,K = C\,a'/a'\,a$; dividing (a) by (b):

$$\frac{K\,G}{K\,E} = \textit{Slip} = \frac{a'\,a}{a'\,a''} \tag{12}$$

i. e. if $a'\,a''$ is divided in 100 equal parts, the per cent slip is $a'\,a$.

Graphical Determination of the Efficiency. It is usually preferable to calculate the efficiency by the separate loss method, but the following graphical construction can also be used. In Fig. 8 produce $L\,C$ to d and draw (1) $d\,d'$ parallel to $C\,O_2$, (2) $h'\,h''$ parallel to $C\,T$ at any convenient distance, (3) $h''\,d'$ parallel to $O'\,X'$. The triangles $d\,G\,W$ and $d\,d'\,h''$ are similar hence (a) $G\,W/d\,W = d\,d'/d'h''$. The similar triangles $d\,E\,W$ and $d\,d'\,h$ give (b) $E\,W/d\,W = d\,d'/d'\,h$; hence, dividing (a) by (b), $G\,W/E\,W = d'\,h/d'\,h''$, which is equivalent to $(E\,W - G\,W)/E\,W = (d'\,h'' - d'\,h)/d'\,h''$, *i. e.* (c) $E\,G/E\,W = h''\,h/d'\,h''$; but the similar triangles $V\,E\,W$ and $d'\,h'\,h''$ give (d) $E\,W/E\,V = d'\,h''/h'\,h''$, hence, multiplying (c) by (d), $E\,G/E\,V =$ efficiency $= h''\,h/h'\,h''$. From h'' lay off a segment $h''\,h''' = h''\,h'$; then

$$\textit{Efficiency} = \frac{h''\,h}{h''\,h'''} \tag{13}$$

i. e. if $h''\,h'''$ is divided into 100 equal parts, the per cent efficiency is $h''\,h$.

Power Factor. As in every a-c. diagram the power factor can be read directly by laying off from the origin of currents O' (Fig. 6) an arbitrary scale of 100 parts in the direction $O'\,Y$ and describing from O' as center the quadrant of a circle Q through the 100th division; the power factor is the ordinate of the point of intersection of the current vector with Q.[6]

APPENDIX

Note 1

Since the core loss current is always very small, the circuit of Fig. 3 is so near to that of Fig. 2 that the truth of this statement may be considered as self-evident, the more so because the method of representing the iron loss by a constant conductance is only a makeshift in both circuits. But even if this inherent inaccuracy of all equivalent circuits is disregarded, the absence of any appreciable difference between Figs. 2 and 3 can be proved by comparing the elements which determine the circles in both cases, *i. e.*, the radii and the coordinates of the centers. For the exact circuit these elements can be found in the "Standard Handbook for Electrical Engineers," 4th ed., p. 515, or in "Arnold, Wechselstromtechnik," vol. 5, p. 94, form. 111. The elements of the locus of Fig. 3 are obtained either by making $g = 0$ in the expressions for the exact locus and adding the current covering the core loss to the ordinate of the center, or directly from Figs. 5 and 6 of the article (the results of both methods are, naturally, identical[7]). These expressions contain elements r_1, x_1, x_2, etc., which

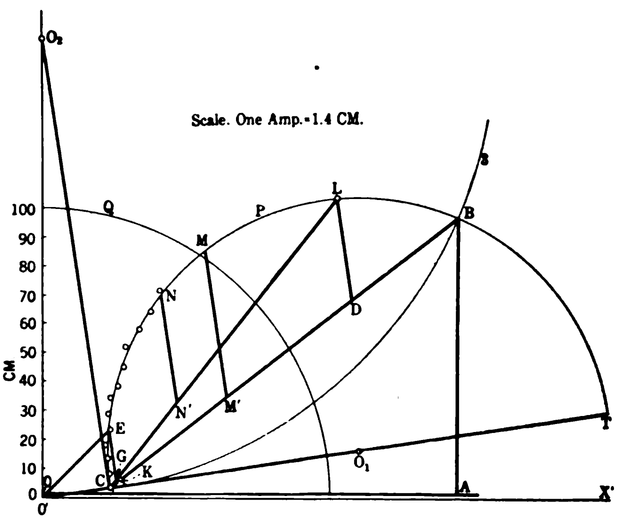

Fig. 9

vary within very wide limits; but by a suitable transformation they can be reduced to the form containing only a few elements varying within comparatively narrow limits (such as leakage coefficient, angle of tilt of the current locus, power factor at no-load, etc.), so that the entire range of combinations occurring in practise can be fairly well covered. A study of this kind made by the writer shows that the difference between the locus of the article and the exact locus is too small to be noticeable, at least in a diagram of usual dimensions (circle diameter = about 8 in.). It is, perhaps, not too much to say that this difference is of the same order of magnitude as the errors due to the inexact assumptions on which all circle diagrams are based.

These conclusions are confirmed by a comparison of the diagram with the results of brake tests made on

6. Note 2.

7. This identity, which is an additional proof of the correctness of the derivation of the locus of Fig. 3, may be of interest in view of the fact that a widely used construction of the tilted locus gives—without proof—an expression for the angle of tilt which differs from the expression (1) of the article even for the theoretical case of a motor without core loss.

a wide range of sizes extending down to the small fractional h.p. motors: In a carefully made test the brake points lie on the locus itself; in less careful commercial tests they may be scattered on both sides of it, but, *if the resistance test is made at the same temperature of the motor as the brake test,* no definite error of tilt can be observed.

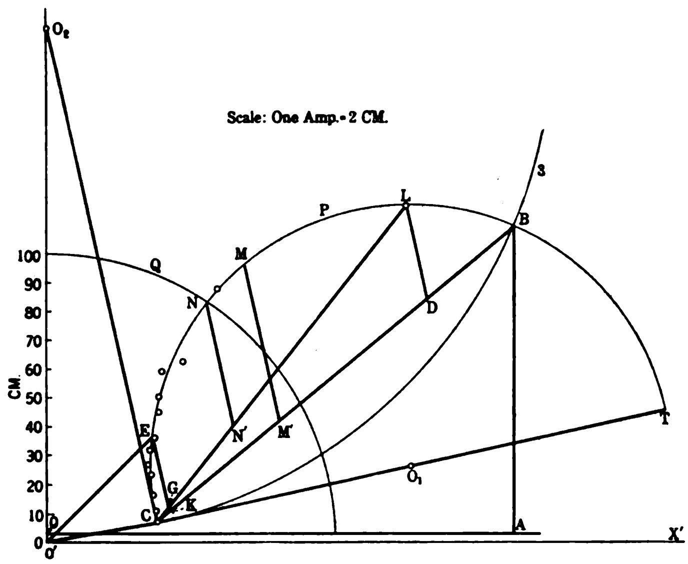

FIG. 10

NOTE 2

The application of the diagram to small motors is illustrated by the following examples (Figs. 9 and 10):

	Example (a) (Fig. 9)	Example (b) (Fig. 10)
Rating	¼ h.p. 220-volt, four-pole, two-phase, 60 ~ squirrel-cage motor	¼ .p., 220-volt, six-pole, two-phase, 60 ~ squirrel-cage motor
r_1	9.8 ohms per phase	12.53 ohms per phase
No-load test	220 = volt, 1.7 = ampere, 99 watts	220 = volt, 1.93 = ampere, 149 watts
Locked test	220 = volt, 10.4 = ampere, 3270 watts	220 = volt, 8.5 = ampere, 2565 watts
Radius of circle 3 $= \frac{V_1}{2 r_1}$	220/19.6 = 11.22 amperes	220/25.06 = 8.78 amperes
$x_s = \sim r_1 \frac{O A}{A B}$ (formula 3)	$9.8 \times \frac{10.35}{6.85} = 14.8$ ohms.	$12.53 \times \frac{8.08}{5.33} = 19$ ohms.
$x_1 = \sim .70\, x_s$	10.4 ohms	13.3 ohms
$X + x_1 = \frac{V_1}{O C}$ (formula 4)	$\frac{220}{1.69} = 130$ ohms	$\frac{220}{1.9} = 115.8$ ohms
$X =$	130 − 10.4 = 119.6 ohms	115.8 − 13.3 = 102.5 ohms
$k = \frac{X + x_1}{X}$	$\frac{130}{119.6} = 1.087$	$\frac{115.8}{102.5} = 1.13$
I_1 (full load) $= O' E$	2.34 amperes	2.62 amperes
$I_2 = C E \times k$	1.4 × 1.087 = 1.52 amperes	1.49 × 1.13 = 1.68 amperes
$r_2 = V_1 \times \frac{D L}{C L^2} \times \frac{1}{k^2}$ (formula 10)	$220 \times \frac{2.55}{9.1^2} \times \frac{1}{1.087^2} = 5.75$ ohms	$220 \times \frac{1.65}{6.98^2} \times \frac{1}{1.13^2} = 5.83$ ohms
$s = \frac{D L}{K E} \times \left(\frac{C E}{C L}\right)^2$ (formula 11)	$\frac{2.55}{1.33} \times \left(\frac{1.4}{9.1}\right)^2 = 4.53$ per cent	$\frac{1.65}{1.34} \times \left(\frac{1.49}{6.98}\right)^2 = 5.6$ per cent
Power factor at full load	71.3 per cent	70.8 per cent
Constant loss = no-load loss $- 2 I_0^2 r_1$	99 − 57 = 42 watts	149 − 93 = 56 watts
Primary copper loss	$2.34^2 \times 9.8 \times 2 = 107$ watts	$2.62^2 \times 12.53 \times 2 = 172$ watts
Secondary copper loss	$1.52^2 \times 5.75 \times 2 = 27$ watts	$1.68^2 \times 5.83 \times 2 = 33$ watts
Total loss at full load	42 + 107 + 27 = 176 watts	56 + 172 + 33 = 261 watts
Output	560 watts	560 watts
Input	560 + 176 = 736 watts	560 + 261 = 821 watts
Efficiency	76.1 per cent	68.2 per cent
$\frac{\text{Starting torque}}{\text{Full-load torque}} = \frac{D L}{K E}$	$\frac{2.55}{1.33} = 1.92$	$\frac{1.65}{1.34} = 1.23$
$\frac{\text{Maximum torque}}{\text{Full-load torque}} = \frac{M M'}{K E}$	$\frac{3.66}{1.33} = 2.76$	$\frac{2.75}{1.34} = 2.05$

The points from the commercial brake tests are also shown in the figures. The error of the method consists in neglecting the drop due to the flow of a current not exceeding $O' O$ in the primary impedance (r_1, x_1).

NOTE 3

It follows from this remark that the primary copper loss component is equal to $E W - K E$ (Fig. 11).

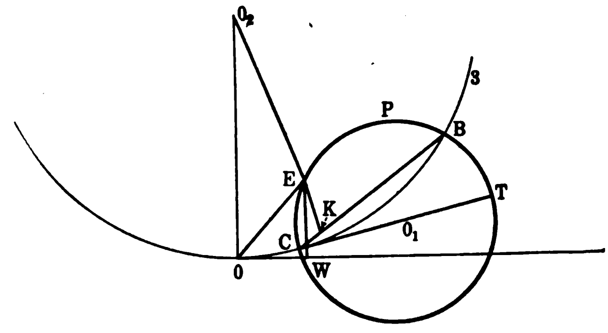

FIG. 11

That such is the case can be proved directly as follows: formula (**7a**) gives

$$O O_2^2 - O_2 E^2 = \frac{V_1}{r_1} \times K E \qquad \textbf{(a)}$$

In the triangle $O\, O_2\, E$, $O O_2^2 - O_2 E^2 + O E^2$

$$= 2 O O_2 \times E W, \text{ i. e., } O O_2^2 - O_2 E^2 + I_1^2 = \frac{V_1}{r_1} \times E W.$$

Substituting in (a)

$$\frac{V_1}{r_1} \times K E + I_1^2 = \frac{V_1}{r_1} \times E W,$$

$$\text{hence } r_1 I_1^2 = V_1 (E W - K E)$$

NOTE 4

The correction is based on the fact that the torque is measured by a segment perpendicular to the dia-

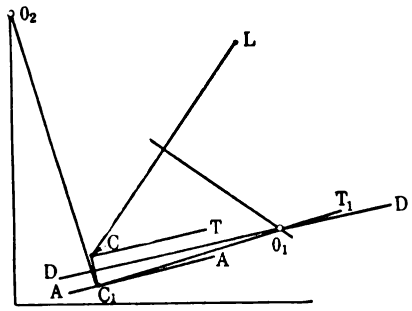

FIG. 12

meter of the locus passing through the zero-torque point (formula **7a**). With the no-load point C conidered as the zero-torque point determine the diameters $C\,T$ as shown in the article; draw $A\,A$ parallel to $C\,T$ and at a distance from it equal to the current component covering the friction, and determine by trial such a point C_1 on $A\,A$ that the perpendicular bisector $D\,D$ of $C\,C_1$, the perpendicular $C_1\,T_1$ to $C_1\,O_2$

$$\left[\text{with } C_1\,O_2 = \frac{V_1}{2\,r_1}\right]$$

and the perpendicular bisector of $C\,L$ meet at the same point O_1; this point is the center of the corrected locus because, with the relative values of $C\,C_1$ and $C_1\,O_2$ occurring in practise the segment $C\,C_1$ remains nearly perpendicular to $C_1\,O_1$, *i. e.*, the no-load point C on the corrected locus is the point corresponding to the friction torque. In practise the construction of the bisector $D\,D$ of the small segment $C\,C_1$ is not accurate, and the correction not very reliable.

Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils

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(*Continued from page* 248 *of JOURNAL for March* 1921.)

LIST OF SYMBOLS

$A_a = \dfrac{1}{k_c\,N\,q}\,(K_a - \epsilon_a\,I^2\,r\,\alpha)$

$A_b = \dfrac{1}{k_c\,N\,q}\,(\gamma\,K_b - \epsilon_b\,I^2\,r\,\alpha)$

$b = \dfrac{x}{1 - \dfrac{\theta_i}{\theta_m}}$ = constant used in equations for linear variation in iron temperature.

$\dfrac{B_a}{A_a} = \dfrac{K_a\,\theta_i + \epsilon_a\,I^2\,r}{K_a - \epsilon_a\,I^2\,r\,\alpha}$ = temperature of embedded copper if all heat flowed transversely.

Note: Use θ_m instead of θ_i with linear or parabolic variations of iron temperatures.

$\dfrac{B_b}{A_b} = \dfrac{\gamma\,K_b\,\theta_0 + \epsilon_b\,I^2\,r}{\gamma\,K_b - \epsilon_b\,I^2\,r\,\alpha}$ = temperature of copper in ends if all heat flowed transversely.

C_1, C_2, C_3, etc. = integration constants.

D_a = thickness of single wall of insulation in embedded portion—taken as distance from bare copper to tooth.

D_b = thickness of single wall of insulation on ends of coil.

$f = \dfrac{x^2}{1 - \dfrac{\theta_i}{\theta_m}}$ = constant when assuming iron temperature axially to be parabolic.

$G = \dfrac{\theta_m\,K_a}{b\,k_c\,N\,q}$ = constant used with linear variation in iron temperature.

$H = \dfrac{\theta_m\,K_a}{f\,k_c\,N\,q}$ = constant used with parabolic iron temperature axially.

I = current (amperes) per conductor.

$K_a = \dfrac{k_a\,Q_a}{D_a}$ = conductivity constant for particular coil (embedded portion).

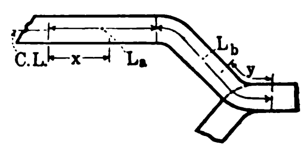
$K_b = \dfrac{k_b\,Q_b}{D_b}$ = conductivity constant for particular coil (end winding portion).

k_a = thermal conductivity of insulation (embedded portion).

k_b = thermal conductivity of insulation (end windings).

k_c = thermal conductivity of copper in watts per unit area per unit length per deg. cent.

k' = emissivity constant for heat dissipation from end windings in watts per unit surface per deg. cent.



L_a = distance from point of max. temp. to end of core; this is usually 1/2 core length.

L_b = half end winding length, at one end only.
L_t = sum of L_a and L_b.
N = number of conductors per coil.
($N\,q$ = cross-section area of copper in one coil.)
Q_a = average surface (in embedded portion) of one coil through which heat flows transversely, per unit length axially.
Q_b = average surface (in end windings) of one coil through which heat flows transversely, per unit length axially.
Q' = outside surface of one coil in end winding per unit length longitudinally.
q = area of cross-section of one conductor.
r = resistance in ohms of copper in one coil per unit length axially at zero deg. cent.
W = heat (expressed in watts) generated between zero point of reference and some other point (x or y).
W_1 = heat (expressed in watts) flowing transversely through insulation from point *0* to x (or y).
W_2 = heat (expressed in watts) flowing longitudinally along copper from point x (or $y + d\,y$) to point $x + d\,x$ (or y).
x = distance from point of max. temp. (usually center of core) to point x.
y = distance from point of min. temp. (taken as extreme end) to point y.

Greek Letters

α = temperature coefficient of copper = 0.00427 at zero deg. cent.

$$\beta = \frac{\sqrt{A_b}\tanh\sqrt{A_b}\,L_b}{\sqrt{A_a}\tanh\sqrt{A_a}\,L_a}$$

$$\gamma = \frac{1}{1 + \dfrac{K_b}{k'\,Q'}}$$

Δ = current density in copper amperes per unit area.
ϵ_a = eddy current ratio for embedded portion = ratio of actual loss to nominal $I^2 R$ (See Gilman's formulas and curves A. I. E. E., June, 1920)
ϵ_b = eddy current ratio for end winding portion.

$$\theta_{a0} = \frac{B_a}{A_a}$$

θ_a = temperature, deg. cent. of copper, at a point x in embedded portion.

$$\theta_{b0} = \frac{B_b}{A_b}$$

θ_b = temperature, deg. cent. of copper at a point y in end winding.
θ_s = temperature, deg. cent., of external surface, at a point y in end windings.
θ_i = temperature of iron adjacent to coils at a point x axially, or the average iron temperature when constant iron temperature is assumed.
θ_L = temperature of copper at end of core.
θ_m = temperature of iron, maximum, when parabolic or linear variation of iron temperature is assumed.
θ_{max} = maximum temperature of copper (embedded portion).

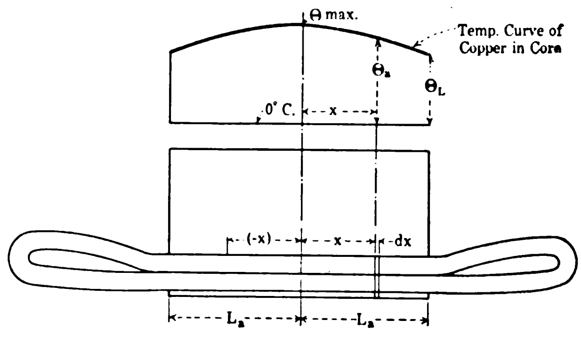


FIG. 1

θ_{min} = minimum temperature of copper (end windings)
θ_0 = temperature of air striking end windings.
θ_{av} = average temperature of winding.
ρ = resistance of unit volume of copper at zero deg. cent. (= 0.625×10^{-6} ohms per inch per sq. in.)

CASE I—CONSTANT IRON TEMPERATURE STEADY STATE

If the machine has run for a long enough period of time to secure constant temperatures (steady state), power expressed in watts may be used instead of energy, expressed in joules or calories, for the heat generated, dissipated, etc. Calling W the heat generated by $I^2 R$ and eddy currents in the copper, the total heat generated from $x = 0$ to $x = x = \int_0^x d\,W$.

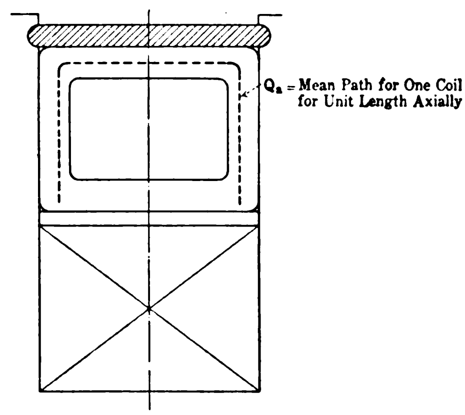


FIG. 2

(See Fig. 1.) This heat must either flow transversely through the insulation, or longitudinally along the copper toward the coil ends. If W_1 is the transverse flow, that heat flow from 0 to $x = \int_0^x d\,W_1$. After

deducting the transverse heat flow from the total generated heat, the remainder must be the longitudinal heat flow; or if W_2 is the heat which flows longitudinally beyond x,

$$W_2 = \int_0^x d\,W - \int_0^x d\,W_1 \qquad (1)$$

The loss in thin lamina $d\,x$ is:

$$d\,W = \frac{\epsilon_a\,\rho\,(1 + \alpha\,\theta_a)\,I^2\,N\,d\,x}{q} \qquad (2)$$

Considering the average heat path through the insulation to have area of Q_a for unit length axially, the area for length "dx" is $Q_a\,dx$, and the traverse heat flow is (Fig. 2):

$$d\,W_1 = \frac{k_a\,(\theta_a - \theta_i)\,Q_a\,dx}{D_a} \qquad (3)$$

If "$d\,\theta_a$" is the difference in temperature between the two sides of lamina "dx," the heat flow from one side of the lamina to the other is:

$$W_2 = -\,k_c\,(N\,q)\,\frac{d\,\theta_a}{dx} \qquad (4)$$

The negative sign is used in (4), because θ_a decreases as x increases.

Substituting the values for W, W_1, and W_2 from (2), (3), and (4) in (1), and differentiating,

$$-\,k_c\,N\,q\,\frac{d^2\,\theta_a}{d\,x^2} = \frac{\epsilon_a\,\rho\,(1 + \alpha\,\theta_a)\,I^2\,N}{q} - \frac{(\theta_a - \theta_i)\,k_a\,Q_a}{D_a} \qquad (5)$$

Or,

$$\frac{d^2\,\theta_a}{d\,x^2} - \frac{1}{k_c\,N\,q}\left(\frac{k_a\,Q_a}{D_a} - \frac{\epsilon_a\,\rho\,I^2\,N\,\alpha}{q}\right)\theta_a = -\left(\frac{\epsilon_a\,\rho\,I^2\,N}{q} + \frac{k_a\,Q_a}{D_a}\,\theta_i\right)\frac{1}{k_c\,N\,q} \qquad (6)$$

Writing

$$A_a = \frac{1}{k_c\,N\,q}\left(\frac{k_a\,Q_a}{D_a} - \frac{\epsilon_a\,\rho\,I^2\,N\,\alpha}{q}\right) = \frac{1}{k_c\,N\,q}\,(K_a - \epsilon_a\,I^2\,r\,\alpha) \qquad (7)$$

and

$$B_a = \frac{1}{k_c\,N\,q}\left(\frac{k_a\,Q_a}{D_a}\,\theta_i + \frac{\epsilon_a\,\rho\,I^2\,N}{q}\right) = \frac{1}{k_c\,N\,q}\,(K_a\,\theta_i + \epsilon_a\,I^2\,r) \qquad (8)$$

equation (6) becomes:

$$\frac{d^2\,\theta_a}{dx^2} - A_a\,\theta_a = -\,B_a \qquad (9)$$

Or,

$$\frac{d^2}{dx^2}\left(\theta_a - \frac{B_a}{A_a}\right) - A_a\left(\theta_a - \frac{B_a}{A_a}\right) = 0$$

Considering $\left(\theta_a - \frac{B_a}{A_a}\right)$ as the dependent variable a general solution will be recognized as:

$$\left(\theta_a - \frac{B_a}{A_a}\right) = C'\,e^{\sqrt{A_a}\,x} + C''\,e^{-\sqrt{A_a}\,x}$$

Since $e^u = \cosh u + \sinh u$

and $e^{-u} = \cosh u - \sinh u,$

the solution in more convenient form may be written as:

$$\theta_a = C_1 \cosh \sqrt{A_a}\,x + C_2 \sinh \sqrt{A_a}\,x + \frac{B_a}{A_a} \qquad (10)$$

In most machines, the temperature is a maximum for $x = 0$, that is at the center of the core. That is, one terminal condition is that $\frac{d\,\theta_a}{d\,x} = 0$ for $x = 0$.

$$\frac{d\,\theta_a}{d\,x} = \sqrt{A_a}\,C_1 \sinh \sqrt{A_a}\,x + \sqrt{A_a}\,C_2 \cosh \sqrt{A_a}\,x = 0$$

Thus $C_2 = 0$ for $x = 0$.

The other terminal condition is determined by making $\theta_a = \theta_L$ for $x = L_a$ (see Fig. 1). Method for evaluating θ_L is given subsequently.

$$\theta_L = C_1 \cosh \sqrt{A_a}\,L_a + \frac{B_a}{A_a}$$

Or $$C_1 = -\,\frac{\theta_{a0} - \theta_L}{\cosh \sqrt{A_a}\,L_a}$$

Where θ_{a0} has been written for $\frac{B_a}{A_a}$.

Then $$\theta_a = \theta_{a0} - \left(\frac{\theta_{a0} - \theta_L}{\cosh \sqrt{A_a}\,L_a}\right)\cosh \sqrt{A_a}\,x \qquad (11)$$

Putting $x = 0$ for maximum temperature,

$$\theta_{max} = \theta_{a0} - \frac{(\theta_{a0} - \theta_L)}{\cosh \sqrt{A_a}\,L_a} \qquad (12)$$

For very long cores, $\cosh \sqrt{A_a}\,L_a$ increases and becomes so large that the temperature at the middle of the core becomes:

$$\theta'_{max} = \theta_{a0} = \frac{B_a}{A_a} = \frac{\left(\frac{k_a\,Q_a}{D_a}\right)\theta_i + \frac{\epsilon_a\,\rho\,I^2\,N}{q}}{\frac{k_a\,Q_a}{D_a} - \frac{\epsilon_a\,\rho\,I^2\,N}{q}\,\alpha} = \frac{K_a\,\theta_i + \epsilon_a\,I^2\,r}{K_a - \epsilon_a\,I^2\,r\,\alpha} \qquad (13)$$

Equation (13) is quite important, as it is the expression for transverse heat flow without considering the longitudinal flow, and takes into account the influence of the temperature coefficient α. If α is neglected, (13) becomes:

$$\theta'_{max.} = \theta\,i + \frac{\epsilon_a\,I^2\,r}{K_a} = \theta\,i + \frac{D_a}{k_a\,Q_a}\,\epsilon_a\,I^2\,r \qquad (14)$$

This is a well-known form, being the sum of the iron temperature and the transverse thermal drop.

In order that θ_L be evaluated, it is essential to consider the heat flow from the embedded portions of the coils to the ends, and then the flow along the copper, as well as the transverse flow in the ends and the heat dissipation from the coil-end surfaces must be brought into the equations. The equations for temperatures in the end windings must be combined with those applying to the embedded portion. The assumption was made in solving the heat flow problem for the embedded portions that the temperature of the outside of the coil in contact with the iron was the same as the temperature of the iron, $\theta\, i$. The parallel assumption for the ends is scarcely admissible, inasmuch as the temperatures of the outside surfaces of the coil-ends are somewhat higher than the surrounding air.

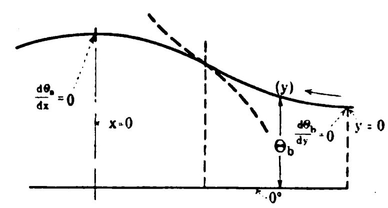


FIG. 3

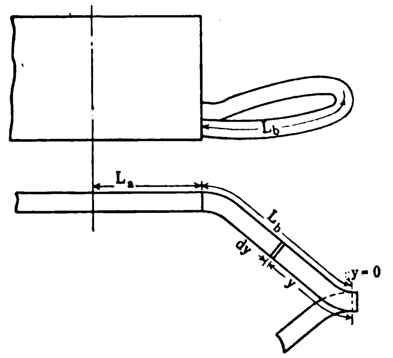


FIG. 4

Calling k' the emissivity from the coil end surfaces in watts per unit surface per degree difference in temperature between the surfaces and the surrounding air, Q' the surface per unit length of end connection, and $d\,W_1$ the watt dissipation to the air in length $d\,y$, the difference in temperature between the coil-end surface and surrounding air is:

$$(\theta_s - \theta_0) = \frac{1}{k'\,Q'}\;\frac{d\,W_1}{d\,y}$$

And as previously,

$$d\,W_1 = \frac{k_b\,(\theta_b - \theta_s)\,Q_b\,d\,y}{D_b}$$

Combining these two equations,

$$d\,W_1 = \frac{(\theta_b - \theta_0)\,k_b\,Q_b\,Q'\,k'\,d\,y}{k'\,Q'\,D_b + k_b\,Q_b}$$

$$= (\theta_b - \theta_0)\;\gamma\;\frac{k_b\,Q_b}{D_b}\;d\,y \qquad (15)$$

Where $\gamma = \dfrac{k'\,Q'\,D_b}{k'\,Q'\,D_b + k_b\,Q_b}$

$$= \frac{1}{1 + \dfrac{k_b\,Q_b}{D_b}\;\dfrac{1}{k'\,Q'}} = \frac{1}{1 + \dfrac{K_b}{k'\,Q'}} \qquad (16)$$

The heat generated in thin lamina $d\,y$, is, as before:

$$d\,W = \frac{\epsilon_b\,\rho\,(1 + \alpha\,\theta_b)\,I^2\,N}{q}\;d\,y \qquad (17)$$

Taking y to be zero at the end of coil (Fig. 4), and to be positive to the left, it is clear that the heat (expressed in watts) that flows along the copper from the point $y + d\,y$ to the point y is:

$$W_2 = +\,k_c\,N\,q\;\frac{d\,\theta_b}{d\,y} \qquad (18)$$

In this case W_2 is positive because θ_b decreases as y decreases.

Evidently, the heat that flows into the copper longitudinally at point y (from left to right), (W_2), + the heat generated in copper from o to y, $\left(\int_o^y d\,W\right)$, must flow through the insulation to the outside surface of the coil where it is dissipated (by forced air convection currents in the usual case)[8]. That is:

$$W_2 + \int_{y=o}^{y=y} d\,W = \int_{y=o}^{y=y} d\,W_1 \qquad (19)$$

Substituting in (**19**) from (**15**), (**17**) and (**18**),

$$k_c\,N\,q\;\frac{d\,\theta_b}{d\,y} + \frac{\epsilon_b\,\rho\,I^2\,N}{q}\int_o^y (1 + \alpha\,\theta)\,d\,y$$

$$= \frac{\gamma\,k_b\,Q_b}{D_b}\int_o^y (\theta_b - \theta_0)\,d\,y \qquad (20)$$

Differentiating and combining,

$$\frac{d^2\,\theta_b}{d\,y^2} - \frac{1}{k_c\,N\,q}\left(\frac{\gamma\,k_b\,Q_b}{D_b} - \frac{\epsilon_b\,\rho\,I^2\,N}{q}\,\alpha\right)\theta_b$$

$$= -\,\frac{1}{k_c\,N\,q}\left(\frac{\gamma\,k_b\,Q_b}{D_b}\;\theta_0 + \frac{\epsilon_b\,\rho\,I^2\,N}{q}\right) \qquad (20)$$

Or

$$\frac{d^2\,\theta_b}{d\,y^2} - A_b\,\theta_b = -\,B_b \qquad (21)$$

Where

$$A_b = \frac{1}{k_c\,N\,q}\left(\frac{\gamma\,k_b\,Q_b}{D_b} - \frac{\epsilon_b\,\rho\,I^2\,N}{q}\,\alpha\right)$$

8. Another way is to consider y as negative, reverse limits of integrals, and W_2 then as negative. That is, however, slightly more difficult to follow, and has, therefore, not been employed. The result is the same.

$$= \frac{1}{k_c N q} (\gamma K_b - \epsilon_b I^2 r \alpha) \quad (22)$$

and

$$B_b = \frac{1}{k_c N q} \left(\frac{\gamma k_b Q_b}{D_b} \theta_0 + \frac{\epsilon_b \rho I^2 N}{q} \right)$$

$$= \frac{1}{k_c N q} (\gamma K_b \theta_0 + \epsilon_b I^2 r) \quad (23)$$

Equation (**21**) is of same form as equation (**9**), so that a general solution is:

$$\theta_b = C_3 \cosh \sqrt{A_b}\, y + C_4 \sinh \sqrt{A_b}\, y + \frac{B_b}{A_b} \quad (24)$$

The terminal conditions for evaluating the constants of integration C_3 and C_4 are that for $y = 0, \frac{d\theta}{dy} = 0$ (that is, the temperature is at minimum value for $y = 0$); and that $\theta_b = \theta_L$ for $y = L_b$.

As for the embedded portion, the first condition gives $C_4 = 0_1$ and the second:

$$C_3 = \frac{\theta_L - \theta_{b0}}{\cosh \sqrt{A_b} L_b}$$

Therefore,

$$\theta_b = \theta_{b0} + \frac{(\theta_L - \theta_{b0})}{\cosh \sqrt{A_b} L_b} \cosh \sqrt{A_b}\, y \quad (25)$$

Where θ_{b0} has been written for $\frac{B_b}{A_b}$

The minimum temperature is for $y = 0$:

$$\theta_{min} = \theta_{b0} + \frac{(\theta_L - \theta_{b0})}{\cosh \sqrt{A_b} L_b} \quad (26)$$

With very long ends, L_b approaches infinity, so that

$$\theta'_{min} = \theta_{b0} = \frac{\gamma K_b \theta_0 + \epsilon_b I^2 r}{\gamma K_b - \epsilon_b I^2 r \alpha} \quad (27)$$

Equation (**27**) is similar to (**13**) and is the expression for temperature when the generated heat at any spot flows transversely through the insulation, uninfluenced by any longitudinal flow.

The equation for temperature in the embedded portion may now be united with the equation for temperature in the ends. The curves for temperatures for the two portions join at point $x = L_a$, or $y = L_b$. (The continuation of those curves beyond that point are shown by the dotted curves in Fig. 3). The heat flowing from the embedded portion to the ends at the point $x = L_a$ is $- k_c N q \left. \frac{d\theta_a}{dx} \right]_{x = L_a}$ (equation (**4**), and the heat received by the ends at $y = L_b$ is $+ k_c N q \left. \frac{d\theta_b}{dy} \right]_{y = L_b}$ (equation (**18**)). These two must be equal to each other. Substituting for θ_a from (**11**) and for θ_b from (**25**), performing the differentiation, equating and substituting L_a for x and L_b for y, the value of θ_L is obtained after simplifying:

$$\theta_L = \frac{\theta_{a0} + \dfrac{\sqrt{A_b} \tanh \sqrt{A_b} L_b}{\sqrt{A_a} \tanh \sqrt{A_a} L_a} \theta_{b0}}{1 + \dfrac{\sqrt{A_b} \tanh \sqrt{A_b} L_b}{\sqrt{A_a} \tanh \sqrt{A_a} L_a}} \quad (28)$$

Writing

$$\beta = \frac{\sqrt{A_b} \tanh \sqrt{A_b} L_b}{\sqrt{A_a} \tanh \sqrt{A_a} L_a} \quad (28a)$$

and

$$\theta_L = \frac{\theta_{a0} + \beta \theta_{b0}}{1 + \beta} \quad (29)$$

With the use of equation (**29**), θ_a, θ_{max}, θ_b and θ_{min} may be evaluated by substituting for θ_L in (**11**), (**12**), (**25**) and (**26**) respectively; or θ_L may be eliminated between (**29**) and the other equations, and the following obtained:

$$\theta_a = \theta_{a0} - \left(\frac{\theta_{a0} - \theta_{b0}}{\cosh \sqrt{A_a} L_a} \right) \frac{\beta}{(1 + \beta)} \cosh \sqrt{A_a}\, x \quad (30)$$

$$\theta_{max} = \theta_{a0} - \frac{(\theta_{a0} - \theta_{b0})}{\cosh \sqrt{A_a} L_a} \cdot \frac{\beta}{(1 + \beta)} \quad (31)$$

$$\theta_b = \theta_{b0} + \left(\frac{\theta_{a0} - \theta_{b0}}{1 + \rho} \right) \frac{\cosh \sqrt{A_b}\, y}{\cosh \sqrt{A_b} L_b} \quad (32)$$

In many machines, $\sqrt{A_a}$ may be taken equal to $\sqrt{A_b}$, and L_a equal to L_b; then $\beta = 1$, and the arithmetical work is simplified somewhat. Then

$$\theta_L = \frac{\theta_{a0} + \theta_{b0}}{2} \quad \text{and}$$

$$\theta_{max} = \theta_{a0} - \frac{\theta_{a0} - \theta_{b0}}{2 \cosh \sqrt{A_a} L_a}, \text{ etc.}$$

The temperature measured by resistance is the average temperature, which may be calculated as:

$$\theta_{av} = \frac{1}{L_a + L_b} \left[\int_{x=0}^{x=L_a} \theta_a\, dx + \int_{y=0}^{y=L_b} \theta_b\, dy \right]$$

Substituting for θ_a and θ_b from (**30**) and (**32**), integrating, and simplifying, calling $L_a + L_b = L_t$,

$$\theta_{av} = \frac{1}{L_t} \left[\theta_{a0} L_a + \theta_{b0} L_b + \left(\frac{\theta_{a0} - \theta_{b0}}{1 + \beta} \right) \left(\frac{\tanh \sqrt{A_b} L_b}{\sqrt{A_b}} - \frac{\beta \tanh \sqrt{A_a} L_a}{\sqrt{A_a}} \right) \right] \quad (33)$$

For the slot portion,

$$\theta_{av} = \theta_{a0} - \left[\left(\frac{\theta_{a0} - \theta_{b0}}{L_a} \right) \left(\frac{\beta}{1 + \beta} \right) \frac{\tanh \sqrt{A_a} L_a}{\sqrt{A_a}} \right] \quad (33a)$$

If A_a be taken equal to A_b, and L_a equal to L_b,

$$\theta_{av} = 1/2\,(\theta_{a0} + \theta_{b0}) \qquad \textbf{(33b)}$$

That is, under the assumptions, the average temperature is simply the arithmetical mean of the maximum and minimum copper temperatures obtainable with very long coils.

Equations Derived From the Preceding

Before leaving the equations for constant core temperature, a number of other solutions will be treated. The first will be to show how some of the equations given in the foregoing reduce to some forms previously derived. The second will be the derivation of an equation for calculating the temperature of the external surface of the coil-ends while the machine is in operation under steady conditions. The third will be the derivation of equations for calculating (a) the heat (in watts) flowing along the copper at any point; (b) the heat flowing through the insulation between the center and any points; (c) the heat generated between the center and any point.

If in equation (**6**), the temperature coefficient α be taken as zero, and assume that the wall of insulation offers so much resistance to the flow of heat that there is longitudinal flow only, that is, if Q_a be taken equal to zero, the equation reduces to:

$$\frac{d^2\,\theta}{d\,x^2} = -\frac{\epsilon_a\,\rho}{k_c}\left(\frac{I}{q}\right)^2 = -\frac{\epsilon_a\,\rho}{k_c}\,\Delta^2 \qquad \textbf{(34)}$$

For the first integral,

$$\frac{d}{d\,x}\left(\frac{d\,\theta}{d\,x}\right) = -\frac{\epsilon_a\,\rho}{k_c}\,\Delta^2, \quad \text{or}$$

$$\frac{d\,\theta}{d\,x} = -\frac{\epsilon_a\,\rho}{k_c}\,\Delta^2\,x + C_5$$

Integrating again,

$$\theta = -\frac{\epsilon_a\,\rho}{2\,k_c}\,\Delta^2\,x^2 + C_5\,x + C_6$$

When $x = 0$, $\theta = \theta_{max}$. Therefore $C_6 = \theta_{max}$.

When $x = 0$, $\frac{d\,\theta}{d\,x} = 0$. Therefore $C_5 = 0$.

Hence the equation becomes:

$$\theta = \theta_{max} - \frac{\epsilon_a\,\rho}{2\,k_c}\,\Delta^2\,x^2 \qquad \textbf{(35)}$$

If $x = L_a$, and $\theta = \theta_L$

$$\theta_{max} = \theta_L + \frac{\epsilon\,\rho\,\Delta^2}{k_c}\;\frac{L^2}{2} \qquad \textbf{(36)}$$

This is a well-known equation.

If similar assumptions are made, except that α be not taken as zero,

$$\theta_{a0} = \frac{B_a}{A_a} = -\frac{1}{\alpha}\ (\text{for } Q_a = 0), \qquad \text{and}$$

$$\sqrt{A_a} = \sqrt{-\frac{\epsilon_a\,\rho\,I^2\,\alpha}{k_c\,q^2}} = j\,\Delta\sqrt{\frac{\epsilon_a\,\rho\,\alpha}{k_c}}$$

where $j = \sqrt{-1}$ and $\Delta = \frac{I}{q}$

Substituting in equation (**12**), and remembering that $\cosh j\,u = \cos u$, the expression for this special case becomes:

$$\theta_{max} = \frac{1/\alpha + \theta_L}{\cos\left(\Delta\,L_a\sqrt{\frac{\epsilon_a\,\rho\,\alpha}{k_c}}\right)} - \frac{1}{\alpha} \qquad \textbf{(37)}$$

It is interesting to compare equation (**37**) with an equation in the paper by H. D. Symonds and Miles Walker: "The Heat Paths in Electrical Machinery" Institution of Elec. Eng. 1912. Using same values for constants as they used, $1/\alpha = 273$, $\epsilon_a = 1$, $\Delta =$ amp. per sq. cm., $\rho = 1.6 \times 10^{-6}$, $k_c = 3$, and taking θ in absolute deg. cent. (**37**) becomes:

$$\theta_{max} = \frac{\theta_L}{\cos\left(\frac{4.43}{10^5}\,\Delta\,L_a\right)}, \qquad \textbf{(37a)}$$

the same as in their paper.

The temperature of the coil end surface may be calculated while the machine is in operation—to check the ordinary thermometer measurements, the location of the thermometer bulb (y) being known, by solving the equations preceding equation (**15**) for $\theta_e\left(\text{thus eliminating } \frac{d\,W_1}{d\,y}\right)$

$$\theta_e = \frac{K_b\,\theta_b + k'\,Q'\,\theta_0}{K_b + k'\,Q'} \qquad \textbf{(38)}$$

In using this equation it is necessary to first determine the internal temperature θ_b at the particular point on the end windings by means of equation (**25**) or (32). The formula is not applicable after shut-down, because then the internal temperatures no longer show the temperature gradients as given by the equations derived, but heat flows from high to low temperatures, thus equalizing, to some extent, the copper temperatures. The external surface temperatures are influenced somewhat by this equalization, and that is one reason why the thermometers on the coil ends frequently show an increase in temperature after shut-down.

The heat flow along the copper is [equation (**4**)] from $x = 0$ to $x = x$ given by $W_2 = -\,k_c\,N\,q\,\frac{d\,\theta_a}{d\,x}$.

Substituting for θ_a from (**30**), and differentiating,

$$(W_2)_a = k_c\,N\,q\,\sqrt{A_a}\,\beta\,\frac{(\theta_{a0} - \theta_{b0})}{(1+\beta)}\;\frac{\sinh\sqrt{A_a}\,x}{\cosh\sqrt{A_a}\,L_a} \qquad \textbf{(39a)}$$

The transverse heat flow is [equation (3)]:

$$(W_1)_a = \int_0^x K_a (\theta_a - \theta_i)\, d x = K_a \Big[(\theta_{a0} - \theta_i)\, x$$

$$- \frac{(\theta_{a0} - \theta_{b0})}{\sqrt{A_a}} \; \frac{\beta}{(1 + \beta)} \cdot \frac{\sinh \sqrt{A_a}\, x}{\cosh \sqrt{A_a}\, L_a} \Big] \quad \textbf{(40a)}$$

The heat generated between $x = 0$ and $x = x$ is

$$(W)_a = \int_0^x \frac{\epsilon_a \rho I^2 N}{q} (1 + \alpha\, \theta_a)\, d x$$

$$= \epsilon_a I^2 r \Big[(1 + \alpha\, \theta_{a0})\, x$$

$$- \frac{\alpha\, (\theta_{a0} - \theta_{b0})}{\sqrt{A_a}} \left(\frac{\beta}{1 + \beta} \right) \left(\frac{\sinh \sqrt{A_a}\, x}{\cosh \sqrt{A_a}\, L_a} \right) \Big] \quad \textbf{(41a)}$$

$\left(\text{For } x = L_a, \; \frac{\sinh \sqrt{A_a}\, x}{\cosh \sqrt{A_a}\, L_a} \text{ becomes } \tanh \sqrt{A_a}\, L_a \right)$

Similar equations may be derived for the ends as follows:

$$(W_2)_b = k_c N q \sqrt{A_b}\, \frac{(\theta_{a0} - \theta_{b0})}{(1 + \beta)} \; \frac{\sinh \sqrt{A_b}\, y}{\cosh \sqrt{A_b}\, L_b} \quad \textbf{(39b)}$$

$$(W_1)_b = \gamma K_b \Big[(\theta_{b0} - \theta_0)\, y + \frac{(\theta_{a0} - \theta_{b0})}{\sqrt{A_b}\, (1 + \beta)} \; \frac{\sinh \sqrt{A_b}\, y}{\cosh \sqrt{A_b}\, L_b} \Big] \quad \textbf{(40b)}$$

$$(W)_b = \epsilon_b I^2 r \Big[(1 + \alpha\, \theta_{b0})\, y + \frac{\alpha\, (\theta_{a0} - \theta_{b0})}{\sqrt{A_b}\, (1 + \beta)} \; \frac{\sinh \sqrt{A_b}\, y}{\cosh \sqrt{A_b}\, L_b} \Big] \quad \textbf{(41b)}$$

It may also be of interest to determine the rate of generation at any point; this is given from equations (**2**) or (**17**), thus:

$$\frac{d W}{d x} = \epsilon_a I^2 r\, (1 + \alpha\, \theta_a) \text{ watts per unit length.}$$

$$\frac{d W}{d y} = \epsilon_b I^2 r\, (1 + \alpha\, \theta_b) \quad \text{" \quad " \quad " \quad "}$$

Similarly the rate of flow of heat transversely through the insulation is from (**3**) and (**15**):

$$\frac{d W_1}{d x} = K_a\, (\theta_a - \theta_i) \text{ watts per unit length.}$$

$$\frac{d W_1}{d y} = \gamma K_b\, (\theta_b - \theta_0) \quad \text{" \quad " \quad " \quad "}$$

Case II. Linear Variation of Iron Temperature Steady State

In some machines, as for example in certain axially ventilated armatures, the core and tooth temperatures are at maximum value at the center, and decrease in linear relation from the center to the end of the core, as indicated in the upper part of Fig. 5. The equation of the straight line may readily be written, if the values of the temperature are known at two points, say for $x = 0$, and for $x = L_a$, thus:

$$\theta_i = \theta_m \left(1 - \frac{x}{b} \right) \quad \textbf{(42)}$$

θ_m is the maximum tooth temperature, and b is a constant.[9] The transverse heat flow is (see equation (**3**)):

$$d W_1 = (\theta_a - \theta_i)\, \frac{k_a Q_a}{D_a}\, d x$$

$$= \left(\theta_a - \theta_m + \theta_m \frac{x}{b} \right) \frac{k_a Q_a}{D_a}\, d x \quad \textbf{(43)}$$

The loss in thin lamina $d x$ and the longitudinal flow are the same as before (see equations (**2**) and (**4**)). Also the fundamental equation co-ordinating $d W$, $d W_1$ and W_2 is the same as previously (equation (**1**)). Substituting for $d W$, $d W_1$, and W_2 in equation (**1**):

$$- k_c N q\, \frac{d\, \theta_a}{d x} + \int_0^x \left(\theta_a - \theta_m + \frac{\theta_m}{b} x \right) \frac{k_a Q_a}{D_a}\, d x = \int_0^x \frac{\epsilon_a \rho I^2 N (1 + \alpha\, \theta_a)}{q}\, d x$$

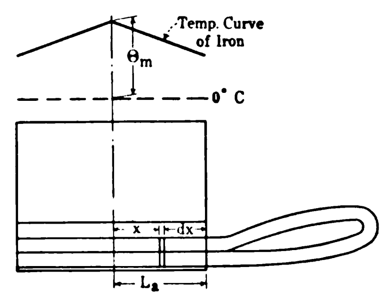


Fig. 5

Differentiating and combining,

$$\frac{d^2\, \theta_a}{d x^2} - \left(\frac{k_a Q_a}{D_a} - \frac{\epsilon_a \rho I^2 N \alpha}{q} \right) \frac{1}{k_c N q}\, \theta_a = \frac{\theta_m}{b}\, \frac{k_a Q_a}{D_a}\, \frac{1}{k_c N q}\, x$$

$$- \left(\frac{\epsilon_a \rho I^2 N}{q} + \frac{k_a Q_a}{D_a}\, \theta_m \right) \frac{1}{k_c N q} \quad \textbf{(44)}$$

$$\text{Or} \quad \frac{d^2\, \theta_a}{d x^2} - A_a\, \theta_a = G\, x - B_a \quad \textbf{(45)}$$

Where A_a and B_a have the same values as previously, (equations (**7**) and (**8**)), except that θ_m appears instead of θ_i, and

$$G = \frac{\theta_m}{b}\, \frac{k_a Q_a}{D_a}\, \frac{1}{k_c N q} \quad \textbf{(46)}$$

Equation (**45**) may be written:

---

9. "b" has been placed in the denominator to simplify numerical calculations.

$$\frac{d^2}{dx^2}\left(\theta_a - \frac{B_a}{A_a}\right) - A_a\left(\theta_a - \frac{B_a}{A_a}\right) = G\,x$$

This linear differential equation may be solved by the well-known method of undetermined coefficients, and a general solution is:

$$\theta_a = C_7 \cosh\sqrt{A_a}\,x + C_8 \sinh\sqrt{A_a}\,x - \frac{G}{A_a}\,x + \frac{B_a}{A_a} \qquad (47)$$

As in the case for constant core temperature, one terminal condition may be taken as $\frac{d\,\theta}{d\,x} = 0$ for $x = 0$. Then:

$$C_8 = \frac{G}{A_a\sqrt{A_a}} \qquad (48)$$

And the other terminal condition is $\theta_a = \theta_L$ for $x = L_a$:

$$C_7 = \frac{-\,\theta_{a0} + \theta_L + \frac{G}{A_a}\,L_a - \frac{G}{A_a\sqrt{A_a}}\sinh\sqrt{A_a}\,L_a}{\cosh\sqrt{A_a}\,L_a} \qquad (49)$$

Where θ_{a0} has been written for $\frac{B_a}{A_a}$. The solution may now be written as:

$$\theta_a = \theta_{a0} + \frac{G}{A_a\sqrt{A_a}}\sinh\sqrt{A_a}\,x - \frac{G}{A_a}\,x - \left[\theta_{a0} - \theta_L + \frac{G}{A_a}\left(\frac{\sinh\sqrt{A_a}\,L_a}{\sqrt{A_a}} - L_a\right)\right]\frac{\cosh\sqrt{A_a}\,x}{\cosh\sqrt{A_a}\,L_a} \qquad (50)$$

As in deriving equation (**28**), the slope of the curve for the embedded portion $\left(-\frac{d\,\theta_a}{d\,x}\right)$ for $x = L_a$, is equal to the slope for the ends $\left(+\frac{d\,\theta_b}{d\,y}\right)$ for $y = L_b$, obtained by differentiating equation (**25**), (the condition for longitudinal flow from the embedded portion at the end of the core being equal to the heat received by the ends at the same point). Thus:

$$-\frac{G}{A_a}\cosh\sqrt{A_a}\,L_a + \frac{G}{A_a} + \left[\theta_{a0} - \theta_L + \frac{G}{A_a}\left(\frac{\sinh\sqrt{A_a}\,L_a}{\sqrt{A_a}} - L_a\right)\right]\sqrt{A_a}\tanh\sqrt{A_a}\,L_a = (\theta_L - \theta_{b0})\sqrt{A_b}\tanh\sqrt{A_b}\,L_b$$

Bringing in β as given by equation (**28a**), the above equation may be written as:

$$\theta_L = \frac{1}{1+\beta}\left(\theta_{a0} + \beta\,\theta_{b0} - \frac{G}{A_a}\left[L_a - \frac{\sinh\sqrt{A_a}\,L_a}{\sqrt{A_a}} + \frac{\cosh\sqrt{A_a}\,L_a - 1}{\sqrt{A_a}\tanh\sqrt{A_a}\,L_a}\right]\right)$$

The expression in brackets may be reduced to:

$$L_a + \frac{-\sinh^2\sqrt{A_a}\,L_a + \cosh^2\sqrt{A_a}\,L_a - \cosh\sqrt{A_a}\,L_a}{\sqrt{A_a}\sinh\sqrt{A_a}\,L_a} = L_a - \frac{\cosh\sqrt{A_a}\,L_a - 1}{\sqrt{A_a}\sinh\sqrt{A_a}\,L_a}$$

Then:

$$\theta_L = \frac{1}{1+\beta}\left[\theta_{a0} + \beta\,\theta_{b0} - \frac{G}{A_a}\left(L_a - \frac{\cosh\sqrt{A_a}\,L_a - 1}{\sqrt{A_a}\sinh\sqrt{A_a}\,L_a}\right)\right] \qquad (51)$$

This value of θ_L could be substituted in equation (**50**), and θ_a and θ_{max} found; or if substituted in equations (**25**) or (**26**), the temperatures of the ends may be found. The resulting expressions are quite complicated, and they are consequently not given here. It is believed best, to solve (**51**) and then substitute the numerical value found in the other equations.

If in equation (**50**), $x = 0$, $\theta_a = \theta_{max}$.

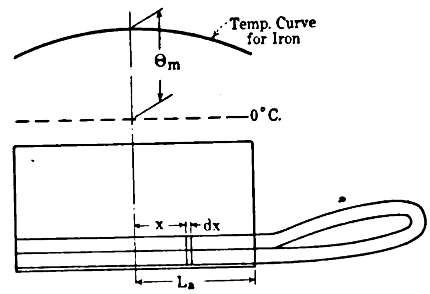


FIG. 6

$$\theta_{max} = \theta_{a0} - \left[\theta_{a0} - \theta_L + \frac{G}{A_a}\left(\frac{\sinh\sqrt{A_a}\,L_a}{\sqrt{A_a}} - L_a\right)\right]\frac{1}{\cosh\sqrt{A_a}\,L_a} \qquad (52)$$

It will be noted that these equations reduce to those for constant core temperature if $G = 0$.

CASE III. PARABOLIC VARIATION OF IRON TEMPERATURE. STEADY STATE

In most machines, especially those with radial ventilation, the core and tooth temperatures may be approximately represented by a parabola, with its maximum value at the center of the core, as indicated in Fig. 6. The equation of this curve for temperature may be written, if the values of θ_i are known at two points, say for $x = 0$, and for $x = L_a$; thus, if "f" is a constant,

$$\theta_i = \theta_m\left(1 - \frac{x^2}{f}\right) \qquad (53)$$

The transverse heat flow is:

$$d W_1 = (\theta_a - \theta_i) \frac{k_a Q_a}{D_a} d x$$

$$= \left(\theta_a - \theta_m + \theta_m \frac{x^2}{f} \right) \frac{k_a Q_a}{D_a} d x \qquad (54)$$

Substituting this value of $d W_1$ and those for $d W$ and W_2 (as found in equations (2) and (4) in equation (1),

$$- k_c N q \frac{d \theta_a}{d x} + \int_0^x \left(\theta_a - \theta_m + \frac{\theta_m x^2}{f} \right) \frac{k_a Q_a}{D_a} dx$$

$$= \int_0^x \frac{\epsilon_a \rho I^2 N (1 + \alpha \theta_a)}{q} d x$$

Differentiating and combining,

$$\frac{d^2 \theta_a}{d x^2} - (K_a - \epsilon_a I^2 r \alpha) \frac{1}{k_c N q} \theta_a =$$

$$\frac{\theta_m K_a}{f k_c N q} x^2 - (K_a \theta_m + \epsilon_a I^2 r) \frac{1}{k_c N q} \qquad (55)$$

Or

$$\frac{d^2 \theta_a}{d x^2} - A_a \theta_a = H x^2 - B_a \qquad (56)$$

Where A_a and B_a are the same as previously (equations (7) and (8)), except that θ_m appears instead of θ_i, and

$$H = \frac{\theta_m K_a}{f k_c N q} \qquad (57)$$

A general solution of this linear differential equation is:

$$\theta_a = C_9 \cosh \sqrt{A_a}\, x + C_{10} \sinh \sqrt{A_a}\, x$$

$$+ \frac{B_a}{A_a} - \frac{H}{A_a} x^2 - \frac{2 H}{A_a^2} \qquad (58)$$

When $x = 0$, $\frac{d \theta}{d x} = 0$, whence $C_{10} = 0$.

For $x = L_a$, $\theta_a = \theta_L$, whence

$$C_9 = \frac{\theta_L - \theta_{a0} + \frac{H}{A_a} L_a^2 + \frac{2 H}{A_a^2}}{\cosh \sqrt{A_a}\, L_a} \qquad (59)$$

And,

$$\theta_a = \theta_{a0} - \frac{H}{A_a} x^2 - \frac{2 H}{A_a^2} -$$

$$\frac{\theta_{a0} - \left(\theta_L + \frac{H}{A_a} L_a^2 + \frac{2 H}{A_a^2}\right)}{\cosh \sqrt{A_a}\, L_a} . \cosh \sqrt{A_a}\, x \qquad (60)$$

For $x = 0$,

$$\theta_{max} = \theta_{a0} - \frac{2 H}{A_a^2} - \frac{\theta_{a0} - \left(\theta_L + \frac{H}{A_a} L_a^2 + \frac{2 H}{A_a^2}\right)}{\cosh \sqrt{A_a}\, L_a} \qquad (61)$$

Equating the heat flow in the embedded part to that received by the ends at $x = L_a$, and $y = L_b$, after simplifying,

$$\theta_L = \frac{1}{1 + \beta} \left[\theta_{a0} + \beta \theta_{b0} - \frac{H}{A_a} \left(L_a^2 + \frac{2}{A_a} - \frac{2 L_a}{\sqrt{A_a} \tanh \sqrt{A_a}\, L_a}\right)\right] \qquad (62)$$

Having found the numerical value of θ_L, the other quantities, θ_a, θ_{max}, θ_b and θ_{min} may be found by substituting in equations (60) (61), (25) and (26) respectively.

(To be continued)

HIGH-TENSION INSULATOR PORCELAIN

ERRATUM

In the paper on the above subject, by W. D. A. Peaslee, published in the JOURNAL for May, 1920, the statements concerning the "piezo-electric effect of porcelain" should have been credited to Mr. C. C. Trieschel by whom they had been previously published in the *Journal of the American Ceramic Society* February 1919.

HYDROELECTRIC DEVELOPMENT IN CEYLON

Plans for the proposed electrification of the industries of the island of Ceylon, with an outline of the Laxapana-Aberdeen project as given in the report of Mr. J. W. Meares, electrical adviser to the Government of India, were published in the JOURNAL for September, 1920, page 843. Information has since been received that the Government of Ceylon has approved Mr. Meares' recommendations relative to the development of the Laxapana-Aberdeen hydroelectric scheme, and has ordered detailed surveys to be made.

The *Journal of The Franklin Institute*, for January, 1921, contains a long illustrated paper by R. D. Duncan, entitled "Recent Attainments in Wired Radio." Wired Radio refers to the use for communication purposes of high-frequency currents guided by wires. Mr. Duncan is a radio engineer in the Signal Corps, U. S. Army.

E. R. SHUTE, traffic engineer, Western Union Telegraph Co., New York, has returned from a trip to various technical colleges throughout the country, which he took for the purpose of scheduling the possible supply of engineering graduates for communication work.

JOURNAL OF THE American Institute of Electrical Engineers

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. PITTSBURGH MEETING
April 16, 1921

The 369th Institute meeting will be held in Pittsburgh, Pa., on Saturday, April 16, 1921. This meeting, under the auspices of the Pittsburgh Section of the A. I. E. E., will be a joint session with the Association of Iron and Steel Electrical Engineers.

The morning will be given over to an inspection of the Colfax station of the Duquesne Light Company and will be followed by a luncheon at the plant. The Board of Directors will also hold its meeting at the plant during the morning. A special train will leave Pittsburgh for the Colfax Station at 10:00 a. m.

The afternoon session will be held in the Auditorium of the Chamber of Commerce at Pittsburgh and will be devoted to the presentation of a paper descriptive of the Duquesne Light plant at Colfax by D. L. Galusha and C. W. E. Clarke, both of Dwight P. Robinson & Co.

An informal dinner will be served at the William Penn Hotel at 6:00 p. m. followed by the second technical session at the hotel, with two papers descriptive of the problems of 25-60 cycle conversion, by B. G. Lamme of the Westinghouse Co. and D. M. Petty of the Bethlehem Steel Co.

A complete program with titles of papers, etc. follows. The Institute paper by Messrs. Galusha and Clarke and that by Mr. Lamme are printed elsewhere in this issue of the JOURNAL.

PROGRAM

10:00 a. m. Inspection Colfax Station, Duquesne Light Co.
Special train leaves Pittsburgh, Penn. R. R. depot at 10:00 a. m.

11:00 a. m. Board of Directors Meeting, at Colfax

12:30 p. m. Luncheon at Colfax Station

3:00 p. m. Technical Session, Auditorium, Chamber of Commerce, Pittsburgh
Colfax Power Station of the Duquesne Light Company by D. L. Galusha and C. W. E. Clarke, of Dwight P. Robinson & Co.

6:00 p. m. Informal Dinner, William Penn Hotel

8:00 p. m. Technical Session, William Penn Hotel
The Frequency Problem in the Steel Industry by B. G. Lamme of the Westinghouse Elec. and Mfg. Co.
Some Results in the Change of 60-Cycle to 25-Cycle Energy by D. M. Petty of the Bethlehem Steel Company.

A. I. E. E. ANNUAL MEETING

The 307th meeting of the A. I. E. E. will be held in the Engineering Societies Building, New York, May 20, 1921. This is the Annual Meeting of the Institute, at which the result of the annual elections is announced and the report of the Board of Directors is presented. A technical program to be announced later will follow the business session.

FUTURE SECTION MEETINGS

Baltimore.—April 15, 1921. Subject: "The Problem of the Electric Motor Car and Its Relation to the Electrical Industry." Speaker: Dr. Charles P. Steinmetz, General Electric Company.

Chicago.—April 25, 1921. Joint meeting with the Electrical and Mining Sections of the Western Society of Engineers, and Association of Iron and Steel Electrical Engineers. Subjects: "Diversity Factor of Coal Mining Loads" by Mr. Carl Lee, E. E., Peabody Coal Company; "Power Distribution Systems for Coal Mines" by Mr. W. C. Adams of Allen & Garcia Company. Both papers will be illustrated with Lantern Slides.

Cleveland.—April 19, 1921. Subject: "The Automatic Railway Substation." Speaker: Mr. L. D. Bale, Cleveland Railway Company.

May 17, 1921. Annual Dinner. Subject: "Some Recent Developments in Scientific Research." Speaker: Mr. C. F. Kettering, The Dayton Engineering Laboratories.

New York.—April 22, 1921. Subject: "Engineering Education" Professor Comfort A. Adams in charge. In addition to the fact that this will be a joint meeting of the N. Y. Section A. I. E. E. and Metropolitan Section A. S. M. E., it will also be the Annual Business Meeting of the N. Y. Section of the Institute at which the results of the election of officers for the year 1921-22 will be announced. Such other business as required by the By-Laws will be transacted. Meeting will be held at 8 p. m. sharp in Auditorium, Engineering Socieites Building, 33 West 39th Street, New York.

San Francisco.—April 29, 1921. Subject: "Toll Line Practise." Speaker: Mr. J. E. Heller, Pacific Telephone & Telegraph Company.

Schenectady.—April 15, 1921. Subject: "Illumination." Speaker: Mr. W. D'A. Ryan.

Vancouver.—May 6, 1921. Subject: "Electric Power in Pulp and Paper Mills." Speaker: Mr. T. H. Crosby.

WASATCH MOUNTAINS FROM LIBERTY PARK SALT LAKE CITY

THE A. I. E. E. ANNUAL AND PACIFIC COAST CONVENTION MEETS IN SALT LAKE CITY, JUNE 21-24, 1921

Annual and Pacific Coast Convention

Salt Lake City, Utah, June 21-24, 1921

The Thirty-Seventh Annual Convention of the Institute will be held at Salt Lake City, Utah, June 21-24, 1921. For a number of years there has been a constantly increasing demand from the active Institute membership residing in the West that it be given the opportunity to act as host at an Annual Convention. The Board of Directors therefore, gladly acceded to the request adopted at the 1920 Pacific Coast Convention to combine the Annual and Pacific Coast Conventions at Salt Lake City in June, 1921. From the preliminary arrangements outlined by the Utah Section the convention this year should prove particularly interesting and profitable from many view-points. Mr. H. T. Plumb has been appointed Chairman of the Convention Committee and announces the appointment of 24 subcommittees to handle the various details.

Institute headquarters will be located at the Hotel Utah and all technical sessions will be held there.

An outline of the tentative program follows:

Tuesday, June 21

The convention will open on Tuesday morning, June 21, with the Annual Presidential Address by Arthur W. Berresford. A technical session, with the presentation of several papers, under the auspices of the Electrical Machinery Committee will follow. Directly succeeding the technical session a luncheon for the Section Delegates is scheduled. This will serve as an opportunity for the delegates to become acquainted and to discuss points of general interest. Tuesday afternoon there will be a trip on foot past the most interesting historical Latter Day Saints buildings, followed by a short lecture and organ recital in the Tabernacle. At 7:00 p. m. an auto trip has been arranged to reach the famous Wasatch Boulevard at sunset and later to Capitol Hill. A return will be made to the Hotel Utah in time for an informal reception at 9:30 p. m.

Wednesday, June 22

Wednesday morning the second technical session will be held under the auspices of the Industrial and Domestic Power Committee. For the forenoon a special Ladies Entertainment has also been scheduled with perhaps a luncheon at the Literary Club. On Wednesday afternoon a special train will leave from the Oregon Short Line depot at 1:30 p. m. over the Bingham and Garfield Railroad. This trip in addition to magnificent views of Great Salt Lake and Salt Lake Valley will provide an opportunity for Institute members to inspect a typical mining canyon, surface workings of a big mine with mills and smelters. On Wednesday evening it is hoped Prof. Karapetoff will render a piano recital, a feature which will particularly appeal to those members who have heard his recitals at previous conventions.

Thursday, June 23

Thursday morning, the technical session will be under the auspices of the Transmission and Distribution Committee. The Board of Directors will meet at luncheon, Thursday noon, and follow the luncheon with a short business meeting. Thursday afternoon is assigned to "A Look at Salt Lake City" from the sight-seeing autos or on foot with local members as guides. Arrangements will also be made for those who wish to devote the time to golf or tennis. For the after-dinner entertainment Dr. Broaddus will deliver an illustrated lecture on the wonderful can yonsof Utah.

Friday, June 24

Friday morning, June 24, is assigned for the presentation of various miscellaneous technical papers. On Friday afternoon in addition to the finals of the Golf and Tennis Tournaments a trip is planned to the Utah Power and Light Company's Terminal Station, the terminus of three 130,000-volt transmission lines, and said to be the largest outdoor substation in the world. Bathing at Saltair Beach is scheduled from 5:00 p. m. to 7:00 p. m., followed either by a dinner in the Ship Café or an old fashioned basket picnic with dancing for those who wish it.

Trips to Points of Interest

Friday evening will conclude the convention proper but for those who can arrange to stay over there are innumerable trips to be taken to points of great interest and scenic beauty, among which might be mentioned Mt. Timpanogos, Beck Hot Springs, Ogden Canyon, Zion National Park, Grand Canyon of the Colorado and the Natural Bridges and Cliff Dwellings of southeast Utah.

Sports

In addition to the regular time allotted to sports during the convention, it will be possible for members desiring to devote more attention to this feature to arrange for additional tennis or golf. The gymnasium of the Latter Day Saints immediately adjacent to the hotel will probably be available for the free use of members and will afford special bathing and exercise at any time of day.

THE A. I. E. E. MARCH MEETING

The 368th meeting of the A. I. E. E. was held in the Engineering Societies Building, New York, March 11, 1921. The meeting was called to order by Manager Charles S. Ruffner who introduced Mr. H. P. Liversidge, Chairman of the Power Stations Committee, under whose auspices the program was given.

The paper of the evening was entitled "Developments in Conversion Apparatus for Edison Systems," by T. F. Barton and T. T. Hambleton, and was presented by Mr. Barton.

A very complete discussion followed which was opened by a written communication from Mr. B. G. Lamme, read by Mr. Albrecht, and oral discussions by Messrs. A. A. Nimis, F. D. Newbury, A. M. Garrett, Raymond Bailey, Philip Torchio, Selby Haar, H. C. Albrecht and D. W. Roper with closure by Mr. Barton.

A. I. E. E. DIRECTORS MEETING

MARCH 11, 1921

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, March 11, 1921, at 3:00 p. m.

There were present: Past-Presidents C. A. Adams and Calvert Townley, New York; Vice-Presidents Charles S. Ruffner, New York, Charles Robbins, Pittsburgh, L. T. Robinson and C. S. McDowell, Schenectady; Managers Walter A. Hall, Boston, Wm. A. Del Mar, W. I. Slichter, L. E. Imlay, L. F. Morehouse, and E. B. Craft, New York, F. D. Newbury, Pittsburgh; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

The Board ratified the approval by the Finance Committee of monthly bills amounting to $17,997.53.

A report was presented of a meeting of the Board of Examiners held March 4, 1921; and the actions taken on applications at those meetings were approved. Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 161 Students were ordered enrolled; 334 applicants were elected to the grade of Associate; 21 applicants were elected to the grade of Member; 1 applicant was transferred to the grade of Fellow; 12 applicants were transferred to the grade of Member.

The Meetings and Papers Committee reported that a request had been received from the Marine Committee for a meeting in Conjunction with the Society of Naval Architects and Marine Engineers, to be held in New York in November, which request had not yet been acted upon by the Committee.

Attention was called to the policy adopted by the Board of Directors a few years ago of requiring the technical committees to include in their annual reports, in addition to a report of the committee's activities during the year, a brief resume of the progress of the art in the respective field of each committee; and upon the recommendation of the Committee on Coordination of Institute Activities the following resolution was adopted:

RESOLVED: That the policy of including in the annual reports of technical committees a brief resume of the progress of the art in the particular field within the scope of each committee, which was carried out last year in a very commendable manner by several of the technical committees, be reaffirmed as the policy of the Institute—in the hope that gradually these annual technical committee reports may become recognized as authoritative sources of information on the history of electrical engineering development.

Professor C. A. Adams was reappointed a representative of the Institute on the Division of Engineering of the National Research Council, for a term of three years commencing July 1, 1921.

A communication from Mr. Charles S. Ruffner was read, requesting that his name be withdrawn from nomination for the office of President.

The report of the Tellers Committee of its canvass of the nomination ballots received for the offices to be filled at the 1921 annual election, was presented; and the action taken is reported elsewhere in this issue.

A communication from the Secretary of Engineering Foundation, requesting the appointment of a committee to cooperate with the Foundation in its study of industrial education and training, was presented and referred to the Educational Committee.

A communication from the Kelvin Memorial Committee was presented, announcing the award of the first Kelvin Medal to Dr. W. C. Unwin.

In addition to these actions many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

A. I. E. E. ANNUAL ELECTION

At the meeting of the Board of Directors of the Institute, held in New York, March 11th, the report of the Committee of Tellers, giving the result of its canvass of the nomination ballots received for the offices to be filled at the coming annual election, was presented.

This report included the names of all candidates eligible for election, the names of those who received less than 3 per cent of the total nomination vote having been eliminated, in accordance with the requirements of the Constitution.

The Board resolved itself into a Committee of the whole, and an informal discussion followed, at the close of which the Committee arose and reported its recommendations to the Board. The Board then selected a complete ticket of "Directors' Nominees" for the respective offices, in accordance with the provisions of the Constitution. This ticket is as follows:

For President:	William McClellan, Philadelphia, Pa.	
For Vice-Presidents:	District No. 1	W. A. Hall, Boston, Mass.
	District No. 2	N. W. Storer, Pittsburgh, Pa.
	District No. 3	W. A. Del Mar, Yonkers, N. Y.
	District No. 4	C. G. Adsit, Atlanta, Ga.
	District No. 5	J. C. Parker, Ann Arbor, Mich.
	District No. 6	F. W. Springer, Minneapolis, Minn.
	District No. 7	H. W. Eales, St. Louis, Mo
	District No. 8	Robert Sibley, San Francisco, Cal.
	District No. 9	O. B. Coldwell, Portland, Ore.
	District No. 10	F. R. Ewart, Toronto, Ont.
For Managers:		A. G. Pierce, Pittsburgh, Pa.
		R. B. Williamson, Milwaukee, Wis.
		Harlan A. Pratt, New York, N. Y.
For Treasurer:		George A. Hamilton, Elizabeth, N. J.

The election ballots were mailed to the entire membership prior to April 1st, in accordance with the Constitution.

The report of the Committee of Tellers follows:

March 9, 1921

REPORT OF COMMITTEE OF TELLERS ON NOMINATION BALLOTS

To the Board of Directors,
American Institute of Electrical Engineers.

Gentlemen:

This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots

received for officers of the Institute for 1921-1922. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		2396
Rejected on account of bearing no identifying name on outer envelope	52	
Rejected on account of having reached Secretary's office after February 28	71	
Rejected on account of ballot carrying signature of voter	1	124
Leaving as valid ballots		2272

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

William McClellan	1085
Charles S. Ruffner	995
Scattering and blank	192
Total	2272

FOR VICE-PRESIDENTS

District		
No. 1. North Eastern		
	W. A. Hall	1758
	Scattering	98
No. 2. Middle Eastern		
	J. D. Lyon	423
	N. W. Storer	900
	J. B. Whitehead	570
	Scattering	20
No. 3. New York City		
	W. A. Del Mar	1760
	Scattering	96
No. 4. Southern		
	C. G. Adsit	1717
	Scattering	97
No. 5. Great Lakes		
	J. C. Parker	1130
	R. F. Schuchardt	753
	Scattering	30
No. 6. North Central		
	F. W. Springer	1737
	Scattering	85
No. 7. South West		
	H. W. Eales	1669
	Scattering	100
No. 8. Pacific		
	Robert Sibley	1729
	Scattering	87
No. 9. North West		
	O. B. Coldwell	1724
	Scattering	35
No. 10. Canada		
	F. R. Ewart	897
	Julian C. Smith	863
	Scattering	43

FOR MANAGERS

E. T. J. Brandon	785
G. L. Knight	977
H. P. Liversidge	876
A. G. Pierce	1123
Harlan A. Pratt	946
R. B. Williamson	1103
Scattering	193

FOR TREASURER

George A. Hamilton	1772
Scattering and blank	500
Total	2272

(The scattering vote for each office was divided among several candidates, each of whom received less than 3 per cent of the total vote.)

Respectfully submitted,

E. A. SKEHAN, *Chairman*
H. W. PARSONS
H. B. WIER
JOHN D. POLLOCK
W. M. VERNOR
Committee of Tellers

MANUSCRIPTS FOR THE JOURNAL

In carrying out the policy of the Publication Committee of limiting the number of pages of reading matter in each issue of the JOURNAL in order to keep approximately within the pro rata monthly appropriation, the Editorial Department now has on hand a considerable amount of excellent material worthy of publication, when space and funds are available. At a meeting held February 16, the Publication Committee decided that in order to publish as many papers as possible, on a wide variety of subjects within the field of electrical engineering and the allied sciences, it will be necessary that more attention be paid to condensing the ideas expressed. With this object in view, it was voted to bring the conditions which limit the amount of material that may be published (as outlined above) to the attention of the Meetings and Papers Committee, for the purpose of reminding that committee of the desirability of requiring authors to reduce the length of their papers as far as possible without omitting any essential features, and particularly of omitting any non-essential illustrations as the cost of engraving is one of the large items of publishing the JOURNAL.

INSTITUTE PRIZES

At various times the desirability of establishing prizes to be awarded by the Institute to authors of papers has been discussed.

The subject has again been active recently, and at a meeting of the Committee on Coordination of Institute Activities, the following resolutions were adopted and were approved at the January meeting of the Board of Directors and referred back to the Coordination Committee for the formulation of the necessary details of procedure in making the awards:

RESOLVED, that it is the sense of the Committee on Coordination of Institute Activities that it is desirable for the Institute to award prizes annually to the authors of papers within the field of electrical engineering and of the allied arts and sciences; and we recommend that if this policy be approved by the Board of Directors, the Institute look forward to establishing eventually, say, three prizes in the following classifications: (1) papers prepared by enrolled Students of the Institute and which may have been presented at any meeting of the Institute, a Section, or a Branch; (2) papers prepared by a member of the Institute who has never before presented a paper before the Institute or any of its Sections, and which have been presented at a meeting of a local Section; (3) papers prepared by any member of the Institute and presented before any meeting of the Institute, a Section, or a Branch.

RESOLVED, that this Committee recommends to the Board of Directors that a prize of $100. cash and a suitable certificate be awarded each year to the author of the paper which is designated by a duly authorized committee of award as the most worthy original paper presented during the year at a meeting of any Section of the Institute by a member of the Institute who has never before presented a paper before the Institute or any of its Sections.

Thus it will be seen that all papers presented at meetings of Sections of the Institute during the year 1921 by any member of the Institute who has never before presented a paper before the Institute or any of its Sections are eligible for this competition, which is intended to cover the second classification referred to in the first resolution quoted above.

The Coordination Committee also considered a specific offer from the Jeffery-Dewitt Company to donate to the Institute $100. each year for the purpose of establishing a prize for the best paper on a subject within the field of high-tension transmission and distribution. The Committee recommended that

"the offer of the Jeffery-Dewitt Insulator Company be accepted as applying to an award for the calendar year 1921." The Board approved this recommendation and referred the matter back to the Coordination Committee for the purpose of formulating the necessary plan of procedure.

The details for making the award have not yet been announced, but it may be understood that all papers presented before the Institute during the calendar year 1921 within the field of high-tension transmission and distribution are eligible for this award. The procedure to be followed in connection with the award of these prizes will be published in a later issue of the JOURNAL.

FIRST KELVIN MEDAL AWARD

The first Kelvin Medal has been awarded in 1921 to Dr. W. C. Unwin, F. R. S. This medal was established in 1914 with the provision that it be awarded triennially as a mark of distinction to a person who had reached high eminence as an engineer or investigator in the kind of work applicable to the advancement of engineering with which Lord Kelvin was especially identified. It was afterwards decided to defer the first award until after the termination of the World War. The medal is awarded by a committee consisting of the presidents of the principal representative British Engineering Institutions.

Professor William Cawthorne Unwin, LL. D., F. R. S., by his contributions to physical and engineering science and to the literature of engineering, by his pioneer work in connection with engineering education, his wide learning and great ability in the prosecution of research, his devoted enthusiasm for more than fifty years to a bold and consistent advocacy of the application of scientific methods to the solution of engineering problems, has possibly done more than any other living member of the British Empire to establish modern engineering upon a scientific basis.

AMERICAN ENGINEERING COUNCIL

REPORT OF PATENTS COMMITTEE
Engineers Urged to Aid Patent Bill

March 7, 1921.

The Patents Committee of American Engineering Council urges all engineers to give prompt attention to the following:

The bill for the imperatively necessary relief of the Patent Office, after passing the House of Representatives with satisfactory provisions for the Patent Office, failed to pass the Senate at the session just closed with those same provisions, solely because of the presence in it of an unrelated section known as the Federal Trade Commission Section.

The former opposition in the Senate to the Patent Office relief and that which forced the unacceptable reductions in salaries and numbers of examiners and clerks (which the Conference Committee was persuaded to set aside) is largely and seemingly almost wholly overcome. But the opposition in the Senate to the Federal Trade Section is determined and has expressed an intention to prevent the Patent Office from getting the desired relief, unless the Federal Trade Section is removed from the bill.

More than preventing the Patent Office relief, however, the Federal Trade Section is believed to be a dangerous measure in itself. It provides that the Federal Trade Commission may receive assignments of and adminster inventions and patents from governmental employes and is an entering wedge for further legislation to empower the Trade Commission to receive patents from non-governmental inventors or owners. An exclusive license would have to be granted, at least for a few years, to induce any one to undertake the almost always necessary development expense, and the Trade Commission would surely be charged with favoritism in granting such a license. In order to protect its licenses, the Trade Commission would have to sue infringers, most unfortunate activity for the government. The industries would close their doors to the government employes fearing to disclose to them their secrets or unpatented inventions, and research by the industries would be discouraged for fear that government employes, using government facilities, might reach the result first and patent it. The Trade Commission, owning a large body of patents, in case that one of its patents was found to be infringed during or at the close of a frequently very expensive development by private interests would be able to dictate in the license the price at which the article, which was the object of the development, could be sold, or to dictate other similar conditions, thus depriving the development of much of its value; and could even require the licensee, as a condition for granting needed license, to practically destroy some of its unrelated patents, as by licensing the trade generally when it would prefer to retain the monopoly for itself.

The foregoing and other objections would result in making patents less desirable to own or to purchase, and consequently would decrease the incentive to produce inventions, which production is the main purpose of our patent system.

The proposed section is unnecessary for the protection of government employes, since they now have all the rights which non-governmental employes have to patent inventions and to sell them. It is therefore believed that the Federal Trade Commission section should not be enacted into law in any form, even as a separate bill.

The Patents Committee of American Engineering Council requests that you request every member of each of the constituent societies of The Federated American Engineering Societies immediately to write his representative and his two senators and the Chairmen of the Committees on Patents of the Senate and the House of Representatives (without naming the Chairmen, as it is not now known who they will be) urging them to eliminate the Federal Trade Commission Section from the Nolan Patent Office Bill H. R. 11,984 and prevent such section from becoming a law in any form and to reintroduce at the opening of the special session of Congress to begin April 4th and pass the bill at once.

(Signed) EDWIN J. PRINDLE, Chairman, Patents Comm.
J. PARKE CHANNING, Secretary, Patents Comm.
Approved: L. W. WALLACE, Executive Secretary
American Engineering Council.

COMMITTEE ON ELIMINATION OF WASTE IN INDUSTRY

The Committee on Elimination of Waste in Industry came into existence from a speech in Washington by Mr. Hoover, in November:

> It is primary to mention the three-phase waste in production; first, from intermittent employment; second, from unemployment that arises, in shifting of industrial currents; and third, from strikes and lockouts. Beyond this elimination of waste there is another field of progress in the adoption of measures for positive improvement in production.
>
> In the elimination of the great waste and misery of intermittent employment, we need at once coordination in economical groups.

In an executive meeting of The Federated American Engineering Council, Mr. Hoover further discussed the need for an intensive study being made of all causes for industrial waste, emphasizing those factors that contribute to labor, or manpower waste. He suggested to the American Engineering Council, the governing body of The Federated American Engineering

Societies, the advisability of appointing a committee of fifteen carefully selected engineers to undertake a study of waste in industry.

The American Engineering Council readily consented to the request of Mr. Hoover. He then formed the Committee on the Elimination of Waste in Industry.

In selecting the personnel of this committee, care was exercised to secure men of broad experience, of clear concepts, of unbiased attitude towards labor problems and representative of managerial, consultant, educational and editorial activities as well as having a widely distributed and a varied industrial contact.

At the organization meeting of the committee in January, its purpose was stated to be:

First: Determine the cause of labor, material and equipment waste in industry. The material and equipment phases of the problem to be studied only insofar as they may cause labor waste.

Second: Insofar as possible determine the extent of the waste that arises through each major cause.

Third: Suggest means of removing the cause for such waste.

To accomplish the purpose of the committee, it has been found necessary to make studies along the following lines:

First: Organization—that which assigns responsibilities and relationships and the discharge of same.

Second: Engineering—which comprises the design, construction and maintenance of plant, machinery and tools and the design of the product.

Third: Production Control and Cost Control. Under this division fall all the factors relating directly to production and the proper direction and accounting for the same.

Fourth: Physical Factors. This division relates to the storage and inspection of raw and processed materials and to matters of internal transportation. It also includes consideration of the physical condition of the plant as regards lighting, heating, toilet facilities and such like.

The first and third sections, as well as a major part of the fourth, directly relate to the human element in industry. The committee is devoting the major portion of its effort to the factors that affect the human element.

Industries to be Studied. Ten representative industries have been selected. They were selected because of their general importance and interest to the public. The ten selected are:

1. Bituminous coal	6. Paper
2. Building trades	7. Metal trades
3. Transportation	8. Textiles
4. Men's ready-made clothing	9. Shoes
5. Printing	10. Rubber

From three to ten plants of each selected industry are to be visited by an experienced engineer who will secure the information desired by the committee. A carefully proposed list of questions will be placed in the hands of each field worker. The information obtained by the field investigator is to be supplemented by such authoritative data as may now exist in the form of reports made by reliable parties or agencies. Through this means sufficient information is to be secured as to enable the committee to formulate specific conclusions as to the major causes of industrial waste.

Staff. A small staff is to be maintained at headquarters. This staff plans and directs the work. The field work is to be done by engineering firms. The firms are to be carefully selected for their fitness for the work. For example, the investigation of ready-made clothing was assigned to a firm that has had a large experience in that field. Thus the Committee will obtain the benefit of the experience and knowledge of that firm that has had most intimate contact with a given industry. The firms are doing the work at actual cost to them. All profit is being waived.

All authoritative literature upon each general topic is to be carefully searched and digest made by well qualified firms. The headquarters staff will compile all the data and write the final report. The final report is to be reviewed by the committee as a whole. Every effort is to be made to secure authentic and quantitative information. Care will be exercised to prevent any bias or prejudice to influence any phase of the work.

Progress of work. The work of the committee is well under way. Reports on the first investigation in each industry were made on February 21, carrying out the time schedule set February 7th. At a meeting of the Planning Board held on March 1, further reports were presented and plans made for continuing the investigations more intensively. These reports were uniformly encouraging and there is every reason to believe that the investigation will yield information that will have an important bearing on the nation-wide movement inaugurated by the engineer to eliminate waste in American industry. In New York, New England and Pennsylvania the fuel investigation is practically completed.

CURRENT ENGINEERING TOPICS

MUSCLE SHOALS AIR NITRATES CORPORATION

A bill providing for the incorporation of the Air Nitrates Corporation and other special measures for the development of the power project at Muscle Shoals have received much attention from the last session of Congress.

The Air Nitrates Corporation was the subject of long hearing in the Committee and heated debates on the Senate floor. The debates finally became almost entirely along party lines and economic features became a minor consideration. The bill finally passed the Senate after its opponents had succeeded in inserting a provision that the Corporation must earn 5 per cent each year after its establishment. This is a practical impossibility.

When the bill was referred to the House Military Affairs Committee the chairman announced his intention to hold it over until next session, have extensive hearings and if possible take it out of politics. The American Engineering Council has been invited to appear at these hearings to give testimony upon the technical phases of the question.

Another effort was made to get an appropriation of $10,000,000 under the Sundry Civil Bill for the completion of Wilson Dam at Muscle Shoals. This provision threatened to block the passage of the Sundry Civil Bill but it was finally thrown out and the bill passed without it.

It is contemplated at the Capitol that this legislation will come up next session when final disposition will be more readily obtained.

FEDERAL POWER COMMISSION

It will be recalled that the act creating the Federal Power Commission was signed by President Wilson on the last day of the previous session of Congress and was thus saved the necessity of running the legislative gauntlet again last session. It was signed with the express understanding that it would be amended so as to remove the jurisdiction of the Commission from all waters in existing National parks. A bill making this provision effective has been under consideration in both Houses during all of the last session of Congress and was finally passed and signed by the President. (Senate bill No. 4554.)

Other important bills affecting this measure failed, however. They were S. 4529 and H. R. 15126 which carried provision for increased personnel and salaries for the Commission. These were perhaps the most important measures because without their enactment into law, the work of the Commission will be greatly curtailed. It is hoped, however, that they can be brought up for early consideration in the next session of Congress. The House bill has already been favorably reported by the House Committee on Interstate and Foreign Commerce. There is apparently little opposition to it in the House although some

senators are definitely known to be opposed to any extension of the power of the Commission.

At its meeting on February 28, the Commission approved modifications of Regulations Nos. 1-10 which had previously been issued on September 3, 1920, and covered the following subjects:

1. Definition of Terms
2. Applications (General Requirements)
3. Applications for Preliminary Permits
4. Applications for Licenses, Major Projects
5. Applications for Licenses, Minor Projects
6. Applications for Licenses, Major Projects already constructed
7. Declarations of Intention
8. Priorities and Preferences
9. Permits
10. Licenses

It also approved additional regulations 11-20 inclusive covering the following subjects:

11. General Consideration Affecting Approval
12. Project Work
13. Lands Reserved or Classified as Power Sites
14. Annual Charges
15. Benefits from Headwater Improvements
16. Depreciation Reserves
17. Amortization Reserves
18. Expropriation of Excessive Profits
19. Allocation of Earnings
20. Accounts and Reports

These regulations were adopted after four hearings had been held and many modifications made. Many of the recommendations made by the Water Conservation Committee of Engineering Council were embodied in these regulations. These regulations as finally approved were ready for distribution shortly after the middle of March.

One of the last acts of the old Commission which was composed of the outgoing Secretary of War, Interior and Agriculture was to approve and authorize the issue of five preliminary permits, four licenses for complete projects and five licenses for transmission lines.

Nearly 200 applications for permits and licenses have been received by the Commission. These applications cover over 13,000,000 horse power and have come from every section of the country.

PERSONNEL RESEARCH FEDERATION

Under the auspices of the National Research Council and Engineering Foundation, in the building of the National Research Council, Washington, was effected March 15th, the organization of the Personnel Research Federation. This Federation includes in its membership scientific, engineering, labor, management and educational bodies. The Personnel Research Federation has been organized to bring about interchange of research information among the numerous organizations which are engaged in personnel research. It is reported to the new Federation by the Bureau of Labor Statistics, of the Department of Labor, that there are 250 such organizations in the United States. The Personnel Research Federation will collect research information, will encourage research through individuals and organizations and will coordinate research activities.

Temporary officers were elected as follows:

Chairman—Robert M. Yerkes, representing National Research Council.

Vice-Chairman—Samuel Gompers, representing American Federation of Labor.

Treasurer—Robert W. Bruere, representing Bureau of Industrial Research.

Secretary—Alfred D. Flinn, representing Engineering Foundation.

Acting Director—Beardsley Ruml, assistant to the president of Carnegie Corporation of New York.

The aims of the new organization are increased efficiency of all the personnel elements of industry—employer, manager, worker—and improved safety, health, comfort and relationships.

The immediate purposes of the Personnel Research Federation will be to learn what organizations are studying one or more problems relating to personnel and the scope of their endeavors, and to determine whether these endeavors can be harmonized, duplication minimized, neglected phases of the problems considered, and advanced work undertaken.

November 12, 1920, a preliminary conference was held in Washington under the auspices of National Research Council and Engineering Foundation, attended by forty persons, including representatives of national organizations of scientists, engineers, labor, capital, managers, educators, economists and sociologists. The question under discussion was the practicability of bringing about cooperation among the many bodies conducting research relating to men and women in industry and commerce, from management to unskilled labor. Such topics as the relations of persons doing different parts of the work, and the influence of working conditions upon the health, output and happiness of the workers, are examples of those which could be made subjects of research.

Dr. James R. Angell, Past-Chairman of the National Research Council, in an address to the conference summarized in the following words the kinds of problems which should receive attention from the organization then proposed:

> Certain of the hygenic problems of modern industry exemplify cases in which a thoroughly scientific study of causes and effects is possible with convincing conclusions regarding practise which will safeguard the health and vigor of all concerned. Not a few highly important results have already been attained in this field. The effects upon industrial productivity on the one hand, and physical vitality, on the other, of good and bad ventilation, of good and bad light, of high temperatures, of irritant fumes, of dust and other similar features are, theoretically, at least, within the field of scientific analysis, and the ascertainment of demonstrable fact. Similarly, and in a different zone of inquiry, it should be possible to secure thoroughly reliable data regarding the dominant causes of unrest in our industries, of excessive turnover and the like. Many other instances of the same kind will suggest themselves to all who have experience in the industrial field.

The underlying ideas which led to the conference, were (1) the advantages of studying such questions by the scientific method of gathering facts and using them to reach conclusions instead of discussing opinions and propaganda, and (2) the need for cooperation among the organizations and individuals engaged in such studies.

FUNCTIONS AND SCOPE OF THE FEDERATION

1. Collection and dissemination of information through:
   (a) Registration of researches contemplated, in progress, or completed;
   (b) Collection of research information;
   (c) Cataloging and analyzing the research information;
   (d) Collecting and analyzing of methods of instruction and training for personnel work;
   (e) Publication;
   (f) Publicity;
   (g) Consultation and advice, when requested.
2. Stimulation and initiation of research through individuals, organizations and governmental agencies, by:
   (a) Publicity and correspondence;
   (b) Personal contact with research agencies;
   (c) Advice and encouragement in the formation of necessary new agencies,
   (d) Aiding governmental agencies to secure appropriations necessary for them adequately to carry on personnel and employment work;
   (e) Calling special conferences;
   (f) Definition of problems needing investigation.
3. Coordination of research activities through:
   (a) Regular meetings of representatives of cooperating agencies;
   (b) Regular reports of affiliated agencies on work in progress and completed;
   (c) Correspondence and personal consultation.

The Personnel Research Federation is beginning modestly and will extend its efforts as it gains in number of members and in financial support. It does not propose to undertake at the beginning all the functions outlined. The Federation is not another agency for research, but rather a clearing house for the existing agencies.

AMERICAN ENGINEERING STANDARDS COMMITTEE

COPPER SPECIFICATIONS SUBMITTED FOR APPROVAL

The American Society for Testing Materials has submitted the following copper specifications to the American Engineering Standards Committee for approval:

Specifications for Soft or Annealed Copper Wire (B3-15)

Specifications for Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots and Ingot Bars (B4-13)

Specifications for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots and Ingot Bars (B5-13)

Methods for Battery Assay of Copper (B34-20)

The specifications are submitted in accordance with the special provision in the procedure of the Committee, under which important standards in existence prior to 1920 may be approved without going through the regular process followed in new work.

The Committee would be very glad to learn from those interested of the extent to which they make use of these specifications, and to receive any other information regarding the specifications in meeting the needs of the industry.

Specifications B3-15, B4-13 and B5-12 may be found in the 1918 volume and Specifications B34-20, in the 1920 volume, of A. S. T. M. Standards. Copies of these may also be obtained from the American Engineering Standards Committee, 29 West 39th Street, New York. Price 25 cents each.

NATIONAL RESEARCH COUNCIL

BENEFITS DERIVED FROM RESEARCH

In order to carry out the function of stimulating industries to conduct research work, the regular meeting of the Division of Engineering, Friday evening, February 4, 1921. was largely given over to two speakers, Dr. Charles L. Reese, Chemical Director of E. I. du Pont de Nemours and Company, and Mr. A. J. Wadhams, General Superintendent of the International Nickel Company, Orford Works.

Dr. Reese brought out very strikingly the enormous advantages derived by his company from research work. The benefits from one research alone were more than sufficient to pay the expenses of the Research Laboratory for a number of years. Aside from monetary gains Dr. Reese pointed out that the research work of his company (a) resulted in increased safety of employees, (b) enabled the company to keep ahead of the art (c) reduced selling prices of established products in spite of increased cost of labor and raw materials (d) increased output (e) discovered new products, the benefits of which often added to the safety, comfort and happiness of the people of the country (f) conserved materials, (g) advanced the art in a few years equivalent to fifty years of normal experience. Disregarding those benefits which cannot be figured into dollars and cents, which are extremely important, there results to his company in a few years a saving or gain of $84,401,000 against an expenditure of $6,051,000 for research work during this period. (A profit of several times the gain quoted will eventually result from continued manufacture of these products without additional expense for research work.)

Mr. Wadhams talked on research work from an operating man's point of view. He pointed out the difficulties of the research man in the factory where all sorts of "hurdles" were placed for him to jump. In spite of these difficulties, the research man was slowly convincing the practical foreman and superintendent of the value of his work by reduced costs, increased outputs, and improvement of quality. His mission of education is not limited to this task, however, as in a great many cases it is just as hard to capitalize the research laboratory in the eyes of the Board of Directors and convince them of the benefits derived therefrom.

It is interesting to note that a large part of the profits that result from research accrue ultimately to the benefit of the consumer in reduced prices.

Future meetings of the Division will be largely given over to distinguished speakers from other industries, who will deal with the general subject of the benefits derived from research work. Executives of corporations who might advantageously be interested to follow these worthy examples, will be invited to attend these meetings.

ENGINEERING FOUNDATION

ANNUAL REPORT FOR SIXTH YEAR

Following are excerpts from the annual report of the chairman of the Engineering Foundation of United Engineering Society for the year ending February 10, 1921:

Sixth Year

Engineering Foundation has been developing methods and means for accomplishing the purposes for which it was created, "the furtherance of research in science and in engineering and the advancement of the profession of engineering and the good of mankind." Its present limited resources have been most effectively employed in demonstrating the value of certain researches and thus attracting from the interested industries support for the further conduct of such researches. The noteworthy example for the year under review is the investigation of the Fatigue Phenomena of Metals.

Endowment Increase

By letter of October 25, 1920, Ambrose Swasey, of Cleveland, Ohio, added two hundred thousand dollars to his gifts to United Engineering Society for endowment of Engineering Foundation, making the total a half-million dollars. He also gave the income of the new fund from January, 1920.

At the beginning of the year, the Board was faced with a possible deficit of $16,000 by 1922, in carrying out its undertakings with the National Research Council, but Edward Dean Adams, of New York, generously assumed this contingent liability. The financial requirements for the work in hand having been provided by the increased income from endowment, the assumption of contingent liability by Mr. Adams was canceled.

Further increase of endowment has been sought. Many friends of the Foundation have helped. Letters have been exchanged and interviews had with men of large wealth in many parts of our country. Some encouragement has been received. One friend offered to give $50,000 if nine other men would make equal gifts.

Forms for Deed of Gift and Declaration of Trust, after study for more than a year, were adopted December 10, and approved by the Trustees December 21, in accordance with a report by Mr. Edward Dean Adams, prepared with the cooperation of Parker and Aaron, Counsel to United Engineering Society.

Progress on Work in Hand

Study was given to policy as to patents secured in connection with the work of Engineering Foundation, and to standard forms for use in connection with grants of assistance for research projects. A number of important letters on patent policy have been collected and filed. Conclusions have not been reached by the committee, although good progress has been made.

Close relations with National Research Council were continued. Increasing cooperation has been given by the Founder Societies. Other technical societies also have shown appreciation for Engineering Foundation and aided in making its work and needs known.

The Fatigue Phenomena of Metals Research has progressed

at the Engineering Experiment Station of the University of Illinois. Interesting partial results have been secured. Attracted by the facilities created by the financial support of the Foundation and the cooperation of the Division of Engineering of National Research Council with the University of Illinois, the General Electric Company entered into an agreement for an extension of the program to cover nickel steels of special interest to it. For this purpose, the company is contributing $30,000, thus duplicating the grant of the Foundation. It has been reported that other industrial corporations are considering similar action.

Engineering Foundation, the Founder Societies and other technical organizations, together with Federal and State governments, cooperated with the Division of Engineering in establishing an Advisory Board on Highway Research.

An Hydraulic Research Committee has collected information about all important known hydraulic laboratories in our country. From this material, a bulletin is being prepared for publication at an early date.

Dr. E. E. Southard was aided by a small grant in the study of Mental Hygiene of Industry, but his work was stopped in its preliminary stages by his sudden death in February, 1920. An offer from Harvard Medical School to cooperate in resuming these studies was regretfully declined for lack of funds.

Engineering Foundation cooperated with National Research Council in examining the possibilities of bringing about useful cooperation in Industrial Personnel Research.*

Hydraulic Weir Tests conducted at the laboratory of Massachusetts Institute of Technology, Cambridge, by Mr. Clemens Herschel with the aid of funds from Engineering Foundation, produced a new form of weir and a very simple formula for determining the quantity of liquid flowing over the weir. The experiments and results are described in a report submitted by Mr. Herschel in March, 1920. There have been many demands for this Reprint No. 4, not only from all parts of North America, but also from South America, Europe and Asia.

Tests on Wear of Gears were resumed during the summer, at Leland Stanford Junior University, by Professors Guido H. Marx and Lawrence E. Cutter. One set of tests was completed, yielding useful, but, of course, limited results.

New Projects

On the suggestion of the American Society of Mechanical Engineers, there was appointed at the December meeting of the Foundation a committee on Industrial Education and Training to examine the practicability and desirability of an extended investigation of the education and training of men for and in the industries. Sources of funds for this work were indicated. This committee has presented a preliminary report with recommendations for the next steps in the formulation of the problem.

January 4, 1921, a formal application for aid in an investigation of Permanent Magnetism was made by L. M. Dieterich, of New York, for the purpose of establishing principles relating to a novel prime mover. This application is under consideration, and meanwhile, Mr. Dieterich is discussing his fundamental theory with several well-known physicists.

Applications were also made by Cyrus Prosch, of New Jersey, for investigating an improvement in steam engineering for the conservation of coal; by Arthur Pestel, of New York, for investigating a theory of the transmutation of energy; and by F. W. Dean, of Pennsylvania, for extension of tests of efficiency of a unaflow engine and of a marine boiler. These applications were severally declined for various reasons.

The Chairman of the Division of Engineering of National Research Council and other persons have suggested that if funds could be provided specific researches in the following broad fields might be supported by Engineering Foundation, with great advantage to the profession and the industries:

1. Cryogenics, particularly research in characteristics of gas mixtures in relation to liquefaction and separation of gases for industrial purposes.
2. Electrical insulation.
3. Colloidal lubricants and fundamental principles of lubrication.
4. Fundamental study of laws of crystallization of metals, atomic structures and other metallurgical problems.
5. Improvement of utilization of all kinds of fuels.
6. Principles of heat transfer.
7. Landslides and earth pressures.
8. Ceramics.
9. Hydraulics.
10. Industrial education and training.
11. Social industrial engineering.

Some investigations have been made and others are being made in these fields, but much important work remains to be done.

Publications and Publicity

During the year, Engineering Foundation published four pamphlets, being "Reprints" of reports made to it and printed in technical journals.

Publicity for the work and needs of Engineering Foundation has been extended by an engagement, beginning November 1, with Mr. James T. Grady, Director of the Department of Public Information, of Columbia University.

Meetings and Membership

Four regular and two special meetings were held during the year. The meeting on December 10 was preceded by a dinner to Mr. Swasey, at which an engrossed certificate was presented expressing appreciation of his gifts.

Two members of the board died during the year: Edmund Gybbon Spilsbury on May 28, and Dr. Samuel Sheldon on September 5.

A financial statement is appended.

Respectfully,

CHARLES F. RAND,
Chairman.

Financial Statement

FOR YEAR ENDED DECEMBER 31, 1920

The Engineering Foundation Board administers the income from an endowment fund now amounting to $500,000, presented to the United Engineering Society.

CASH RECEIPTS AND PAYMENTS

Funds on hand January 1, 1920:		
Cash in bank	$9,591.42	
U. S. Treasury Certificates	10,000.00	
Total		$19,591.42
RECEIPTS:		
Interest on $500,000 bonds held by United Engineering Society (less collection, custodial and advisory charges)		24,069.76
Interest on daily bank balances		159.68
Interest on U. S. Treasury Certificates		224.25
Total		$44,045.11
PAYMENTS:		
Salaries (Secretary and office force)	$5,063.81	
Miscellaneous office expenses	284.08	
Stationery and printing	295.62	
Traveling expenses	163.04	
Publications	1,801.16	
Publicity	500.00	
Mental Hygiene of Industry research, balance	1,108.70	
Hydraulic Weir Tests, balance	60.47	
Division of Engineering, N. R. C. (office rental and part of salary roll)	8,676.47	
Fatigue Phenomena of Metals research	10,000.00	
Total		$27,953.35
Balance on hand December 31, 1920		$16,091.76

ASSETS AND LIABILITIES

ASSETS:	
Cash in bank December 31, 1920	$1,045.51
Petty cash	15.00
U. S. Treasury Certificates	15,031.25
Total	$16,091.76

LIABILITIES:

Apart from salaries and other routine expenses, the only liabilities of Engineering Foundation are the unexpended balances of appropriations for researches: For Gear Tests, $207.73; for Fatigue Phenomena of Metals, $11,000.

*See PERSONNEL RESEARCH FEDERATION, p. 347 of this issue.

Publications

Publications are issued in two series, in the standard size for scientific societies (7 x 10 inches).

PUBLICATIONS

No. 1. Report on the Origin, Foundation and Scope of the National Research Council, February, 1917.

No. 2. A Progress Report to United Engineering Society, October, 1919.

No. 3. Annual Report for Year ended February 10, 1921.

No. 4. Hydraulic Laboratories in U. S. (In preparation.)

REPRINTS

No. 1. The Mental Hygiene of Industry, March, 1920; from "Industrial Management," February, 1920. Out of print.

No. 2. Trade-Unionism and Temperament, April, 1920; from "Industrial Management," April, 1920. Price, 25 cents.

No. 3. The Modern Specialist in Unrest, June, 1920; from "Industrial Management," June, 1920. Price, 25 cents.

No. 4. An Improved Form of Weir for Gaging in Open Channels, May, 1920; from "American Society of Mechanical Engineers," June, 1920. Price, 35 cents.

RESEARCH NARRATIVES

In January, 1921, the semi-monthly publication was begun of a series of leaflets each containing the story of some research or discovery or notable achievement in science or engineering, very briefly told. There have been printed to date:

No. 1. Isolated Research—Its Handicaps: The Story of Mendelism.

No. 2. Fatigue of Metals: A Story of Cooperation.

No. 3. Utilizing Low-Grade Ores: An Iron Story.

No. 4. Electric Welding: From Lecture Room to Industry.

No. 5. Early Uses of Nickel.

Complete copies of this report may be obtained by addressing Engineering Foundation, 29 West 39th Street, New York, N. Y.

MARINE RULES

RECOMMENDED PRACTISE FOR ELECTRICAL INSTALLATIONS ON SHIPBOARD

The differences between the requirements of various Classification Societies and Insurance Companies in regard to electrical installations on shipboard and the lack of any accepted standard engineering practise for marine installations led the American Institute of Electrical Engineers in 1913 to appoint a Committee on the use of Electricity in Marine Work, now known as the Marine Committee. This Committee besides arranging for papers to be read at the meetings of the Institute to increase the interest of Electrical Engineers in marine problems, also took up the preparation of the Standardization Rules which would represent good engineering practise, and which might be accepted by the Classification Societies. As a result, a set of rules was prepared covering two important divisions; namely Fire Protection Requirements, and Marine Construction Requirements. The first part related primarily to dangers that might arise from fires, and the second part had to do purely with the preservation, maintenance and operation of the electrical plant in its exposure to the conditions existing on shipboard.

These rules were adopted by the Committee of the American Bureau of Shipping and were published as Section 37 of the Rules for building and classing vessels, issued by that Bureau.

This first edition of the Rules did not cover the entire field of the use of electricity on shipboard, and the Committee was, therefore, continued in force, and a more nearly complete Set of Marine Rules has now been prepared. The Committee has made a careful comparison of the Rules issued by the American Bureau of Shipping, the National Board of Fire Underwriters, the Steam Boat Inspection Service of the U. S. Department of Commerce, Lloyd's Register of Shipping, the Institution of Electrical Engineers, Bureau Veritas, Germanischer Lloyd, and Verband Deutscher Elektrotechniker. With several of these Associations, correspondence and personal conferences were carried on.

When the Committee had nearly completed its work on the second Set of Marine Rules, the Regulations for the Electrical Equipment of Ships, First Edition, were issued by the Institution of Electrical Engineers in England. These Rules have substantially the same scope as those prepared by the American Committee, and as there will be some occasion for comparing the engineering practises of the two countries, a slight rearrangement of material has been made to conform more nearly to the order of subjects as given in the English Rules, in order to facilitate comparison.

In the preparation of these rules, consideration has been given to the danger from fire, and to durability and reliability of the electrical apparatus itself, but no attempt has been made to divide the Rules into separate sections of that character.

Certain Mechanical Signaling Systems are included, as it is the custom of many shipyard electrical engineers to supervise the installation of mechanical signaling equipments as well as the electric plant.

The membership of the Committee being drawn from a large variety of shipbuilding, manufacturing and engineering interests, including the U. S. Navy, it is thought that the Rules, as prepared, represent the best practise for this class of work. During the War, a large number of the newer shipyards were represented on the Marine Committee, which gave opportunity for advising them, through the Committee Meetings concerning the best engineering practise as followed by the older yards.

To insure a careful consideration of these Rules sub-committees were appointed to cover various branches of the work, and after each sub-committee had considered its own rules, they were submitted for discussion to the entire Committee, after which they were referred to an Editing Committee of four members to arrange them in suitable form for publication. It is not to be expected that this edition of the Rules contains everything that might be of value relating to electrical installations on shipboard, and it is expected that later editions will be prepared which will be more complete and will include electric propulsion.

In the meantime, any questions concerning Rules, which appear to be of doubtful meaning, may be referred to the Chairman of the Marine Committee of the American Institute of Electrical Engineers, 33 West 39th Street, New York City, and the Committee invites suggestions for improvements or amplifications of these Rules.

No definite arrangements have yet been made for the approval of apparatus and accessories, but it is expected that through the cooperation of the Underwriter's Laboratories, arrangements will be made later by which apparatus or appliances used on shipboard may be inspected and approved.

In the absence of approved standards for Merchant Ships, appliances approved by the Navy Department will in general be satisfactory.

Bound copies of the Rules may be obtained at $1.00 per copy by addressing American Institute of Electrical Engineers, 33 West 39th Street, New York, N. Y.

INSTITUTE YEAR BOOK

The A. I. E. E. 1921 Year Book is available to members, without charge, upon application to the Secretary, 33 West Thirty-ninth Street, New York.

The book contains an alphabetical and geographical catalog of the membership revised to January 1, 1921; also the constitution, by-laws, lists of officers and committees, and considerable additional information relating to the activities of the INSTITUTE.

STANDARDIZATION OF LIGHTING FIXTURES

At a meeting of the Council of the Illuminating Engineering Society held on March 10, 1921 the following resolution was adopted:

Whereas in the opinion of the Council of the Illuminating Engineering Society the project for rendering lighting fixtures readily removable by the employment of suitable electric attachments as discussed at the January meeting of the New York Section of this Society, offers potentiality for large improvement in lighting conditions, and

Whereas realization of the potential value of this project is contingent upon such standardization as will make the electric attachments of fixtures completely interchangeable, and

Whereas failure to so standardize attachments would jeopardize the success of the project entailing untold inconvenience and confusion to the public, be it therefore

Resolved that in the best interest of the public and of the lighting industry the Council hereby urge all concerned to cooperate to the fullest extent in bringing about complete interchangeability of removable lighting fixtures.

PERSONAL MENTION

P. E. Klopsteg is leaving the Leeds & Northrup Company to go with the Central Scientific Company of Chicago.

A. A. King has accepted a position as chief electrician with the Phelps-Dodge Corporation, Copper Queen Branch, Mines Department, Bisbee, Ariz.

George Sutherland has changed from Stone & Webster, Inc., Boston, to the United Electric Light & Power Company, New York.

Wallace B. Kirke has left the General Electric Company to become assistant to the chief electrical engineer of the New York Edison Company.

John H. Bell, telegraph engineer with the Western Electric Company, New York, has returned from London, where he has been for several months on a business trip.

H. C. Wolf, formerly with Arthur Young & Co., Chicago, is now assistant chief engineer with the Public Service Commission of Maryland, Baltimore, Md.

H. E. Driver of the Westinghouse Electric & Manufacturing Co., Chicago, has returned from France and may now be reached at his former address, 32 S. Peoria St., Chicago.

Frederick A. Kolster has changed from the Bureau of Standards, Washington, D. C., to the Federal Telegraph Co., Palo Alto, Cal.

Lee R. Titcomb has left the employ of the Klaxon Company, Newark, N. J., and has engaged in research and consulting work on his own accord, with headquarters at 26 Fulton Street, Bloomfield, N. J.

Harold S. Hughes, electrical contractor, who has been connected with the Camp Signal Office at Camp Funston, Kansas, is now at West Point, N. Y. His address is Box 90, West Point, N. Y.

S. Reyes of Brooklyn, N. Y., and of the Bureau of Insular Affairs, Washington, D. C., sailed on March 1st for the Philippine Islands. His address there will be Bureau of Posts, Manila, P. I.

J. L. McK. Yardley, formerly chief engineer of The Beaver Board Companies, Buffalo, N. Y., resumed association January 1st, 1921, with the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., as general engineer.

George K. Whitworth has severed his connections with the Bethlehem Shipbuilding Corporation of San Francisco, and does not expect to be identified with any firm for the next two years, as he will give his entire time to further studies in engineering. His address is 2415 Bowditch St., Berkeley, Cal.

Ira Dye has given up his position as superintendent of the American Frog and Switch Co., at Hamilton, Ohio, and has opened an office at 430 Lumber Exchange, Seattle, Washington, for the practise of Industrial Engineering in the Puget Sound District.

S. N. Clarkson has resigned from the editorial staff of the *Electrical World* and has opened an office as consulting engineer in the Star Building, St. Louis. Mr. Clarkson will specialize on Public Utility rate matters, public relations and the problems involved in financing and supplying service to rural consumers of electric service.

Charles N. Arnold has been appointed as instructor in Mechanical Engineering in the College of Engineering of the University of Illinois. Mr. Arnold was graduated from the University of Illinois in 1911, after which he worked with several electrical companies, being assistant chief electrician for Armour and Company, 1915-1917; and during the war served as lieutenant in the U. S. Navy on engineering duty.

James W. Owens delivered a lecture on March 18th to the commissioned and civilian technical force of the Bureau of Construction and Repair of the Navy in Washington, D. C., on "The Use of Welding in Ship Construction." For the past three years Mr. Owen has been engaged in extensive research on welding at the Norfolk Yard for this bureau, and supervised the construction of Battle Towing Target No. 60, America's largest welded structure. (A description of this target may be found in *The Welding Engineer* for December, 1920.)

Walter C. Strunk has tendered his resignation in the Mechanical Research & Construction Division of the Motive Power Department of the Interborough Rapid Transit Company, New York, to accept a position in the Stoker Division of the Westinghouse Electric & Manufacturing Company, Lester, Pa. Mr. Strunk started work in 1909 with the Metropolitan Street Railway Company, New York, in the Training School for College Men. After spending two years in the school he entered the electrical department. Since 1912, when the New York Railways Company was reorganized, he has been with the Interborough Rapid Transit Co.

C. G. Young has organized the C. G. Young Company, Inc., consulting engineers, located at 501 Fifth Avenue, New York. Mr. Young, a Fellow of the Institute, has had over thirty years' experience in domestic and foreign fields, covering a wide range of engineering construction. He was for seventeen years with the firm of J. G. White & Co. of New York and London. His extensive traveling on engineering and financial business undertakings has covered practically the entire world; and besides being an authority on electric railways and other electrical construction, he is a specialist on financial examination and reports.

OBITUARY

Francis Robbins Upton, former associate of Thomas A. Edison and first President of the Edison Pioneers, men who worked with Mr. Edison in the early days of the inventor's great successes, died Wednesday, March 10th, 1921, at his home in Orange, N. J., following a lengthy illness.

Mr. Upton, who was a mathematician, assisted Mr. Edison in working out complicated problems as to economy and adaptability of the devices necessary to make a complete system of electric light by incandescence. He was also associated with Mr. Edison in his ore milling and subsequently was interested in quarries and in selling materials for concrete construction.

Mr. Upton was born in Peabody, Mass., July 26th, 1852 and was educated in Phillips Academy, Andover, Chauncey Hall, Boston, Bowdoin College, Princeton Univeristy and Berlin University. He was for many years a member of the Institute and served as Vice President 1889-90 and as Manager 1890-92.

Mr. Upton was twice married. His first wife was Mrs. Elizabeth Fenno Perry. He subsequently married Margaret Adriance Storm, who survives him. The surviving children are Elizabeth Fenno, Curtis Perry, Francis Robbins, Jr., Lucina Eleanor Stuart, one son Frederick Thompson.

George Holt Lukes, general superintendent of the Public Service Company of Northern Illinois, with office in Chicago, died February 18, 1921. Mr. Lukes was born in Racine, Wis., December 6, 1869. He was graduated from the Massachusetts Institute of Technology in 1892, after which he took a short student engineering course at the works of the General Electric Company in Schenectady, and then secured employment with the old Chicago Edison Company as inspector. He became night operating superintendent of this company in 1898. He left the Edison Company in 1902 to become superintendent of the North Shore Electric Company; and when the North Shore and several other public utility companies were combined into the present Public Service Company of Northern Illinois in 1911 he was appointed general superintendent of the new company. Mr. Lukes made his home at the Evanston University Club. He took interest in many subjects, though engineering, especially public utility development, remained his life work. Besides belonging to the Institute, he was a member of the Western Society of Engineers, Illuminating Engineering Society, National Electric Light Association, Chicago Engineers Club, Electric Club of Chicago, University Club of Chicago, Evanston University Club, Glenview Golf Club and Park Lodge No. 833, A. F. & A. M. He was also a life member of the Art Institute of Chicago and a sustaining member of the Chicago Society of Etchers.

Frank A. Pickernell, for many years on the engineering staff of the American Telephone and Telegraph Co., died on February 12, 1921, at his residence in Englewood, N. J. Mr. Pickernell was born in Boston, March 28, 1865, and received his engineering education at the Massachusetts Institute of Technology. He then entered the employ of the American Bell Telephone Co. In 1887 he came to New York as superintendent of equipment for the American Telephone and Telegraph Co., and later played an important part in the opening up of the first long-distance line between New York and Chicago. He retired from active business about two years ago. Mr. Pickernell was one of the early members of the Institute, which he joined in 1890. He was also a member of the Telephone Pioneers of America.

Cecil P. Poole died in Norfolk, Va., on February 23, 1921, where he had gone to reestablish his practise as consulting engineer. Mr. Poole was born in Elizabeth City, N. C., October 16, 1863, and received a high school education, acquiring his later technical knowledge by engineering work and by wide reading. His practical work began with the old Brush arc lighting station at Norfolk, in 1884. Three years later he took charge of the lighting and power plant at Lynchburg, Va., and continued to operate it on his own account under lease after he started contracting engineering, in 1888. In 1895 Mr. Poole became associate editor of the *Electrical World*, and for several years devoted his time to technical writing and editing, becoming editor of the *American Electrician* in 1900. He resumed his engineering work, however, and in 1912 moved to Atlanta, Ga., where he later became identified with the engineering department of the city, being in charge of work of the department of inspection. Mr. Poole was a Fellow of the Institute. The members of the Atlanta Sections of the A. I. E. E. and the A. S. M. E. issued a testimonial in memory of Mr. Poole, with whom they were closely associated during many of the last years of his life.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES FEB 1-28, 1921

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

The Airplane

By Frederick Bedell. N. Y., D. Van Nostrand Co., 1920. 257 pp., front., diagrams, 9 x 6 in. cloth. $3.00.

The first six chapters of this volume contain, in revised form, the material previously published under the titles "Airplane Characteristics" and "The Air Propellor." Seven additional chapters discuss problems of flight, performance and stability. The author's aim has been to present a well-rounded introductory treatment simple in form but reasonably complete and accurate.

American Lubricants from the Standpoint of the Consumer.

By L. B. Lockhart. Second edition, revised and enlarged. Easton, Pa., The Chemical Publishing Co., 1920. 341 pp., illus., tables, 9 x 6 in. cloth. $4.00.

This book is offered to buyers and users of lubricants as an aid in the intelligent selection of oils and greases. It describes the various commercial lubricants, explains the laws of friction, the conditions met in lubricating various classes of machinery and the methods used to satisfy them. Methods for chemical and physical tests are given, and specifications for oils and other lubricants for a greater variety of purposes.

Anlagen zur Gewinnung Von Naturlichen und Kunstlichem Grundwasser.

By Paul Brinkhaus. Munchen and Berlin, R. Oldenbourg, 1920. (Oldenbourg's Technische Handbibliothek, bd. 23) 14 + 227 pp., diagrams, illus., charts, 8 x 5 in., cloth. 20M.

The author differentiates his book from others on the utilization of ground water supplies by the omission of descriptions

of existing works for this purpose, which are of historical rather than practical interest. The present volume deals with practical matters only. The exploration and measurement of ground water supplies, the digging and driving of wells and infiltration galleries, are discussed in detail. The book is intended for young engineers.

APPLIED COLLOID CHEMISTRY; GENERAL THEORY.

By Wilder D. Bancroft. First Edition, N. Y. and Lond., McGraw-Hill Book Co. Inc., 1921. (International chemical series.) 345 pp., illus., 8 x 6 in., cloth. $3.00.

Professor Bancroft here presents the theory of colloids, as an introduction to the study of its application in specific branches of industry. The book discusses absorption, surface tension, coalescence, the preparation and properties of colloidal solutions, jellies and gelatinous precipitates, emulsions, foams, non-aqueous colloidal solutions, fog, smoke, etc.

ASPHALTS AND ALLIED SUBSTANCES.

By Herbert Abraham. Second edition, corrected. N. Y., D. Van Nostrand Company, 1920. 608 pp., illus., diagrams, tables, 9 x 6 in., cloth. $6.00.

This is a comprehensive treatise for makers, sellers and users of asphalts, tars, pitches and their products. It includes the methods used for testing and analyzing raw and manufactured products, information on blending and compounding mixtures, general information on the scope of the use of bituminous materials and on their limitations, and the principles underlying the use of bituminous products for structural purposes. Topics which have been adequately presented in other books have been purposely subordinated to those concerning which little has hitherto been published.

CAMS, ELEMENTARY AND ADVANCED

By Franklin De Ronde Furman. N. Y., John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1921. 234 pp., diagrams, 9 x 6 in. cloth. $3.00.

The first five sections of this book appeared previously under the title "Elementary Cams." To these sections three have been added giving a further development of the subject. The elementary portion gives a classification, an arrangement and a general method of solution of the well-known cams, and also a series of cam factors for base curves in common use. The advanced portion includes the development or use of the logarithmic, cube, circular, tangential and involute base curves, and the establishment of cam factors for those which have general ones.

THE CHEMISTRY OF PLANT LIFE.

By Roscoe W. Thatcher. First edition. N. Y. and Lond., McGraw-Hill Book Co., 1921. (Agricultural and biological publications.) 268 pp., 9 x 6 in. cloth. $3.00

An account of our knowledge of the chemical changes by which the plant cell performs the processes which result in the production of so many substances which are vital to the comfort and pleasure of man. It is intended as a text or reference book, and presupposes an elementary knowledge of chemistry.

COAL WASHING.

By Ernest Prochaska. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 382 pp., illus., diagrams, 8 x 6 in. cloth. $4.00.

In preparing this compendium the author has had in mind the need of the coal operator for a systematic description of modern practise in the art of coal washing. The book opens with a description of the evolution of methods and machines from the beginning. The second and more important section deals in detail with the methods in use today.

CONNECTING INDUCTION MOTORS.

By A. M. Dudley. First edition, N. Y., and Lond., McGraw-Hill Book Co., Inc., 1921. 252 pp., illus., diagrams, 9 x 6 in., cloth. $2.50.

Although the theory of the induction motor has been treated very completely, little has been published concerning the practical details, of which the windings are a prominent part. This work, by an engineer with extensive experience, is for those engaged in operating and repairing these motors. It explains the methods for figuring new windings for old core, locating faults in windings, changing windings to meet varying conditions of voltage and phase, and similar needs which arise.

DIRECT-CURRENT ARMATURE WINDINGS.

By W. E. Henning. First edition. Milwaukee, C. N. Caspar Co. (Practical Electrician Course.) 204 pp., illus., diagrams, tables, 10 x 7 in., cloth. $4.00.

The author states that his object has been to collect practically all of the direct-current armature winding diagrams now scattered through many books, and to present the subject clearly and practically. Mathematical and technical discussions have been simplified and shortened.

ELECTROLYTIC DEPOSITION AND HYDROMETALLURGY OF ZINC.

By Oliver C. Ralston. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 201 pp., front., illus., diagrams, charts, 9 x 6 in., cloth. $3.00.

The author states that while hydrometallurgic zinc processes have scarcely been sufficiently developed to justify an extensive treatise, they are sufficiently standardized to call for a simple text which will set forth present practise and the underlying theory of leaching, purification and electrolysis. This book gives a brief survey of present development and describes the processes and more important plants.

ELEMENTARY DYNAMICS; a Text-Book for Engineers.

By J. W. Landon. Cambridge. University Press, 1920. 246 pp., diagrams, 7 x 5 in., cloth. $3.25. (Gift of The Macmillan Company.)

The author of this text-book believes that many of the beginner's difficulties in grasping the fundamental principles of dynamics arise from an over-emphasis of mathematics. This difficulty he attempts to avoid by emphasizing the physical ideas, whose meaning he explains partly by definition and description, but mainly by worked examples in which formulas are avoided as far as possible.

ELEMENTARY LESSONS IN THE MATHEMATICS OF ELECTRICITY.

By R. W. Kent. Minneapolis, the Dunwoody Institute, 1920. 72 pp., 9 x 6 in., paper. $1.00.

This pamphlet is intended to instruct journeymen and others in the electrical trade in the fundamentals of arithmetic and simple algebra. The ordinary methods of calculation are explained and problems are provided, illustrating their application to electrical calculations.

ELEMENTS OF MECHANISM.

By Peter Schwamb, Allyne L. Merrill, Walter H. James. Third edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 372 pp., diagrams, 9 x 6 in., cloth. $3.50.

After sixteen years, this text-book appears in a thoroughly revised and expanded edition, embodying the changes suggested by its use for instruction at the Massachusetts Institute of Technology and other colleges. It is intended to provide a systematic, clear, practical presentation of the subject, suited to the amount of time usually devoted to it in college courses.

ERTRAGREICHSTER AUSBAU VON WASSERKRAFTEN.

Von Dr. Ing. Leiner. Munchen und Berlin, R. Oldenbourg, 1920. 111 pp., diagrams, 11 x 8 in., paper. 40M.

The author examines the principles which serve as a guide in estimating the probable financial returns from the utilization of a water-power; then he studies the most advantageous method of development, depending upon the constancy or intermittency of the power, the possibility of using reservoirs, and similar factors.

THE ESSENTIALS OF ADVERTISING.

By Frank Leroy Blanchard. First edition. N. Y. and Lond., McGraw-Hill Book Co., 1921. 322 pp., illus., 8 x 6 in., cloth. $3.00.

The purpose of the writer of this book is to outline and discuss, as briefly and as clearly as possible, the fundamental principles upon which advertising practise is based, the preparation of copy, the special advantages of the several mediums employed, the duties of advertising managers, agents and salesmen and such other information as will give the student a comprehensive view of the subject.

FIELD METHODS IN PETROLEUM GEOLOGY.

By G. H. Cox, C. L. Dake and G. A. Muilenberg. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 305 pp., map, illus., tables, 7 x 5 in., cloth. $4.00.

In a volume of pocket size the authors have provided a systematic discussion of the minutiae of field procedure in this specialized branch of engineering geology. The book describes the instruments and methods in general use, discusses the geologic criteria used in correlating beds and indentifying structures, and gives directions for organizing field parties, carrying on work in the field and preparing maps and reports. An appendix contains the necessary tables.

GAGE DESIGN AND GAGE-MAKING.

By Erik Oberg and Franklin D. Jones. First edition, first printing. N. Y., The Industrial Press; Lond., The Machinery Publishing Co., Ltd., 1920. 310 pp., illus., diagrams, 9 x 6 in., cloth. $3.00.

Much, the authors state, has been published on manufacturing practise, but comparatively little on the design and making of the gages used to control manufacturing processes and insure interchangeability in finished parts. Their book is intended to present the principles upon which gage design depends, and to describe the methods of manufacturing, measuring and testing gages.

HYDRO-ELECTRIC DEVELOPMENT.

By J. W. Meares. Lond. and N. Y., Sir Isaac Pitman & Sons Ltd., (Pitman's technical primer series). 90 pp., front., illus., 6 x 4 in., boards. $1.00.

This little primer, based on the author's experience, aims to set down in logical order, the points which require attention in the discovery, reconnaissance and final design of a hydroelectric scheme. It is confined strictly to the hydraulic aspect of the problem, omitting electrical questions and the practical details of plant construction.

DIE KOMPRESSIONS—KALTEMASCHINE.

By W. Koeniger. Munchen und Berlin, R. Oldenbourg, 1921. 204 pp., plates, tables, diagrams, 9 x 6 in., paper. 30M.

This book is based on an extensive investigation of sulfurous-acid refrigerating machines by its author. New views resulted which contributed to a solution of the question why the "wet" process of compression is less efficient than the "dry," and which also led to new methods for the calculation of refrigerating machines. The book is intended for students of the theory of these machines and for designers, and includes both sulfurous-acid and ammonia machines.

KUGELLAGER UND WALZENLAGER IN THEORIE UND PRAXIS.

Von Paul Haupt. Munchen unde Berlin, R. Oldenbourg, 1920. 199 pp., tables, diagrams, 9 x 6 in., paper, 18M.

This work is a summary and extension of the scattered literature on bearings with rolling friction. Besides a theoretical discussion of the laws underlying the construction of ball and roller bearings, current practise is described, and the commercial types are examined critically.

DAS KUGELPHOTOMETER (ULBRICHT'SCHE KUGEL).

Von Richard Ulbricht. Munchen und Berlin, R. Oldenbourg, 1920. 11 pp., 3 plates, diagrams, 10 x 7 in., paper. 24M.

This account of Ulbricht's spherical integrating photometer is based upon the papers which appeared in the *Elektrotechnische Zeitschrift* from 1900 to 1910. The investigations described therein are here presented in more systematic and connected fashion, with such revision and correction as has appeared necessary.

MECHANICAL WORLD YEAR BOOK, 1921.

Manchester and London, Emmott & Co., Ltd. 318 pp., illus., 6 x 4 in., cloth. 2s. 6d.

This inexpensive annual is intended as a convenient pocket reference book for mechanical engineers and shop superintendents. The most used data are given on steam engines and boilers, gas and oil engines, gas producers, the properties of metals, structural iron and steel work, toothed gearing bearings, belting, friction and lubrication, steam fitting, screws and similar subjects. A buyer's directory is included.

METHODS IN METALLURGICAL ANALYSIS.

By Charles H. White. Second Edition, revised. N. Y., D. Van Nostrand Co., 1920. 356 pp., illus., 7 x 5 in., cloth. $3.00.

This is a collection of the methods most frequently used in American metallurgical laboratories, arranged for use by students and works chemists. No previous experience in quantitative analysis is assumed, but sufficient detail is given to meet the needs of beginners.

MEXICO AND THE CARRIBEAN. Clark University Addresses.

Edited by George H. Blakeslee. N. Y., G. E. Steichert & Co. 1920. 363 pp., 9 x 6 in., cloth. $4.00. (Gift of Mr. Kirby Thomas.)

The Clark University Conferences upon International Relations are for the purpose of promoting a more intelligent understanding of our international problems, a more sympathetic appreciation of the attitude of other peoples, and a keener realization of our own international duties. This volume contains the addresses, delivered at the 1920 conference, upon Mexico and the Carribean, by business men, diplomats and others from the United States and the other countries concerned, which present the situation as seen by these experts and contain their recommendations for a national policy. Certain of them, notably Frederic R. Kellogg's upon the Mexican oil situation, and Kirby Thomas's upon business in the Carribean lands, are of special interest to engineers.

NEUE GRUNDLAGEN DER TECHNISCHEN HYDRODYNAMIK.

Von L. W. Weil. Munchen unde Berlin, R. Oldenbourg, 1920. 219 pp., illus., diagrams, 9 x 6 in., paper. 26M.

This work is concerned with some of the problems of hydrodynamics for which no exact elucidation or analytical solution has yet been obtained, as for example, eddies in streams and pipes, the effect of expansions or contractions in channels, orifice problems, water hammer and the theory of turbines and of rotary flow of liquids. The author advances certain principles, based on long theoretical and practical study, which he considers correct and in accordance with experimental results.

THE NEW THERMODYNAMICS; the non-postulated rationale of motive power of heat.

By Jacob T. Wainwright. Privately printed, 1921. 44 pp., 10 x 7 in., boards. (Gift of author.)

Believing that the second law of thermodynamics, which is the foundation for present day teaching of that branch of thermodynamics which treats of the motive power of heat, is untrue, the author presents his arguments for its repudiation. The monograph sets forth his views as to the rationale of the motive power of heat and his grounds for claiming that the Carnot principle conflicts with the principle of the conservation of energy and with observed results.

PATENT LAW.

By John Barker Waite. Princeton, University Press. Lond., Humphrey Milford, 1920. 316 pp., 9 x 6 in., cloth. $5.00.

In this volume the Professor of Law in the University of Michigan Law School presents a concise but complete and thorough discussion and exposition of the principles of patent law, intended for inventors, engineers and all that class of laymen who from time to time want information concerning their rights in respect to patents and inventions. It purports to cover only the substantive law of patents, their nature, validity, effect and their characteristics as property; and the author has attempted to present every issue that has come before the courts.

PERSONAL RECOLLECTIONS OF ANDREW CARNEGIE.

By Frederick Lynch. N. Y., etc., Fleming H. Revell Co., 184 pp., port., 8 x 6 in., cloth. $1.50.

Dr. Lynch's reminiscences cover a phase of Mr. Carnegie's activities that is not so widely known as his beneficences. His love of poetry and music, his religious opinions, interest in international peace, his views on education and similar topics, are set forth as he gave them to his friends.

PRACTICAL LOCOMOTIVE RUNNING AND MANAGEMENT.

By W. George Knight. Second edition, third thousand. Copyrighted 1920 by W. George Knight, Medford, Mass. 541 pp., illus., 8 x 5 in., cloth. $4.00.

This volume explains the construction and operation of the locomotive in detail, describes the accessories in detail and gives instruction in maintenance and methods of repair on the road. The book is intended for those who actually operate and maintain locomotives and is elementary in character.

PRIESTLEY IN AMERICA. 1794-1804.

By Edgar F. Smith, Phila., P. Blakiston's Son & Co., 173 pp., 7 x 5 in., cloth. $1.50.

From contemporary newspapers, documents and books, Dr. Smith has compiled the record of Priestley's life and literary and scientific activites, from his arrival in America until his death.

PRODUCER GAS.

By J. Emerson Dowson and A. T. Larter. Fourth edition. London and N. Y., Longmans Green and Co., 1920. 361 pp., illus., 9 x 6 in., cloth. $7.50.

Contents: Theory of producer gas.—Furnace work.—Heating work.—Engine work.—Suction plants.—Gas from bituminous coal for engine work.—Producer gas from peat.—Gas traction on roads.—Gas propulsion of vessels.—Stand-by losses.—Comparison of gas and steam power.—Fuel.—Analysis of fuel and of producer gas.—Calorific power of solid and gaseous fuels.—Practical notes. Appendixes.

The table of contents shows the scope of this treatise, which

gives a general survey of present practise in the production and utilization of producer gas. This edition has been thoroughly revised.

RED-LEAD AND HOW TO USE IT IN PAINT.

By Alvah Horton Sabin. Third edition, rewritten and enlarged. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Limited, 1920. 139 pp., illus., tables, 8 x 5 in., cloth. $2.00.

Like the preceding editions, this little book sets forth the essential facts concerning the manufacture of red lead, its preparation as a paint and the methods of using it based on thirty years' experience and study. The present edition is rewritten and considerably amplified.

STORAGE BATTERIES.

By C. J. Hawks. Minneapolis, The Wm. Hood Dunwoody Industrial Institute. 157 pp., illus., diagrams, charts, 9 x 6 in., cloth. $2.00.

This description of the theory, construction and operation of storage batteries in intended as an instruction book for the use in industrial schools and workmen's classes. The detailed construction of various types of cells is given, the methods of assembling, charging and testing are explained, with instruction in repair work.

TASCHENBUCH FUR SCHIFFSINGENIEURE UND SEEMASCHINISTEN.

By E. Ludwig and E. Linder. Dritte auflage. Munchen und Berlin, R. Oldenbourg, 1920. 12+502 pp., tables, diagrams, illus., 7 x 5 in., cloth. 24M.

This book is a third edition under a new title and with new compilers, of G. Bauer's "Kalender fuer seemaschinisten." In its present form it is a volume of convenient size, intended for marine engineers, and covering concisely all the mechanical equipment of ships. The volume contains the necessary physical and mathematical tables and formulas, sections on reciprocating steam engines, steam turbines, turbine reducing gear, boilers, boiler accessories, piping, combustion engines, auxiliary mechanical equipment, electrical equipment, measuring instruments, ship construction, navigation, laws and regulations. All these subjects are treated from a modern point of view, particular attention being given to methods likely to be used in the future.

TELEGRAPHY: A DETAILED EXPOSITION OF THE TELEGRAPH SYSTEM OF THE BRITISH POST OFFICE.

By T. E. Herbert. Third edition. Lond., and N. Y., Whittaker & Co., 1916. 20+985 pp., illus., 7 x 5 in., cloth. $6.50. (Gift of Isaac Pitman & Sons.)

This volume is a detailed description of the apparatus and methods used by the British Post Office, intended for students preparing for its examinations. Mathematical methods of exposition have been avoided. The present edition includes the many advances that have come since the issue of the preceding one in 1906, particularly in duplex, multiplex and automatic telegraphy.

A TEXTBOOK OF GEOLOGY.

By Amadeus W. Grabau. Part 1: General geology. N. Y. D. C. Heath & Co. 864 pp., illus., 9 x 6 in., cloth.

Dr. Grabau's treatise is intended as a standard text upon the subject, and while the needs of college classes have been kept in mind during its preparation, the author has also tried to produce a work of value as a work of reference. The volume differs from others of its kind in arrangement and also in the detailed attention given, wherever possible to typical examples of geological phenomena, rather than to generalizations with illustrations drawn from any sources.

TIME TELLING THROUGH THE AGES.

By Harry C. Brearley. N. Y., published by Doubleday, Page & Co., for Robert H. Ingersoll & Bro., 1919. 294 pp., plates, 9 x 6 in., boards. $3.00 (Gift of Robert H. Ingersoll & Bro.)

An interesting popular account of the subject from the earliest times to the present day, with special reference to the American watch industry. In addition to the main story, appendixes give a description of the mechanism of the watch, a bibliography, a chronological list of American watch manufacturers, a list of the chief collections of watches and an encyclopedic dictionary of terms.

A TREATISE ON CHEMISTRY.

By Sir H. E. Roscoe and C. Schorlemmer. Vol. 1. The Non-Metallic Elements. Fifth edition, revised by J. C. Cain. Lond., Macmillan and Co., Ltd., 1920. 968 pp., port., illus., 9 x 6 in., cloth. $9.00.

In this new edition the advances of chemistry during the past nine years have been incorporated so that the work is again up to date. The general style and character of the book has been preserved. It remains a fairly complete statement of the facts of modern chemistry and chemical theory, presented in readable form, with special attention given to the more important processes of technical chemistry and the most approved forms of apparatus employed in them.

TREATISE ON GENERAL AND INDUSTRIAL CHEMISTRY.

By Ettore Molinari, translated from the third Italian edition by T. H. Pope. Part 1. Phila., P. Blakiston's Sons & Co., 1921. 456 pp., illus., diagrams, 10 x 7 in., cloth. $8.00.

This book is characterized by an endeavor to combine, with the theoretical presentation of the subject, an extensive account of industrial processes and some information on the commercial aspects of production. It will be useful as a reference book.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—February 23, 1921. Paper: "Operating History of the Windsor Power Plant." Author: Mr. E. H. McFarland, Manager, Beech Bottom Power Plant. Attendance 47.

Baltimore.—February 25, 1921, Johns Hopkins University. Subject: "The Operating and Economical Advantages of Electric Locomotive." Speaker: Mr. A. H. Armstrong of the Railway and Traction Engineering Department of the General Electric Company. Attendance 120.

Chicago.—February 28, 1921, Western Society of Engineers. Subject: "Dependence of Aerial Transport upon Electricity." Speaker: Mr. Chas. F. Kettering, President, Dayton Engineering Laboratories Company. Attendance 250.

Cincinnati.—March 10, 1921, Assembly Hall, Union Gas & Elec. Co. Mr. W. S. Werner of the Kelley-Koett Mfg. Company, Covington, Ky., gave a very interesting talk on the history of the X-Ray and demonstrated the latest type of X-Ray apparatus. Attendance 60.

Cleveland.—February 15, 1921, Club Rooms of Cleveland Engineering Society. Subject: "Rates for Electrical Service as Viewed in the Light of the Present Economic Trend." Speaker: Mr. Paul M. Lincoln of the Lincoln Electric Company. Attendance 82.

Denver.—February 17, 1921, Albany Hotel. Mr. W. L. Winner, Instructor in Radio Educational Service, Fitzsimmons General Hospital, gave a very instructive talk on the radio telephone, illustrated by blackboard sketches. Mr. Winner gave a demonstration of the operation of a radio telephone which he had installed in the hotel. Music and conversations were transmitted from the hospital at Aurora to the hotel by wireless. The radio telephone in the hotel was equipped with a loud speaking receiving device which enabled everyone of the guests present in the room to hear the music and conversations distinctly. Attendance 200.

Fort Wayne.—February 11, 1921, Chamber of Commerce. Joint meeting with local Section of A. S. M. E. Mr. Calvin W. Rice, Secretary of the American Society of Mechanical Engineers, discussed the opportunities of the engineer in public service and pointed out just how the engineer, by proper organization, could assist the local community in the general solution of engineering problems. Attendance 75.

Indianapolis-Lafayette.—February 25, 1921, Chamber of Commerce Building, Indianapolis. Subjects: "Typical Utility

Service Complaints" by Mr. M. D. Atwater, Public Service Commission of Ind.; "Recent Development in Radio Telegraphy" by Mr. Francis Hamilton, American Radio Relay League. Attendance 75.

Kansas City.—February 25, 1921, University Club. Subject: "Human Engineering." Speaker: Chancellor Lindley of the University of Kansas. Attendance 64.

Los Angeles.—February 18 and 19, 1921, Polytechnic High School Auditorium. Joint meeting with the American Chemical Society and the Mathematics and Science Association. Subject: "The Structure of the Atom." Speaker: Dr. Robert A. Millikan. Attendance 765.

Lynn.—February 16, 1921. Subject: "Some Physical and Engineering Problems Connected with Guns and Projectiles." Speaker: Major Gordon F. Hull of Dartmouth College. The lecture covered the characteristics of air streams of high velocity: the factors determining forces on projectiles and other bodies; measurement of the retardation of a bullet; measurement of expansion of a gun during firing; and factors contributing to the bursting of guns. The talk was illustrated. Attendance 240.

Minnesota.—January 31, 1921, N. W. Telephone Building. Subject: "Problems of Unification of Manual and Automatic Telephone System in the Twin Cities." Mr. J. F. McDermott, Supervisor of the Development Division, discussed what the probable demands would be and the changes necessary to properly serve the public. Mr. C. B. Spring, General Equipment Engineer, from Omaha, explained the various methods of consolidating two systems of this kind, and explained why the present system was installed in the Twin Cities. He also explained fully, with the aid of slides, the operation of both the manual and the automatic systems. Dinner was served by the Northwestern Telephone Company in its cafeteria. Attendance 80.

New York.—February 25, 1921. On the evening of Feb. 25 in the Auditorium of Engineering Societies Building, New York, Dr. Saul Dushman, Research Engineer, General Electric Co. delivered a most interesting lecture on "Theory and Application of Hot Cathode Devices." The lecture was accompanied with interesting laboratory demonstrations of the action of the hot cathode under varying conditions and applications. Slides were shown illustrating various steps in the development of the kenotron and the pliotron. Dr. Dushman also touched on the development of the dynatron and the magnetron. Attendance about 900.

Directly preceding the lecture Chairman H. W. Buck called for a vote or amendment to the N. Y. Section By-laws permitting the earlier nomination and election of officers. Unanimous approval of the changes desired was obtained.

Philadelphia.—February 14, 1921, Engineers Club of Philadelphia. Informal dinner followed by addresses by Messrs. W. C. L. Eglin of the Philadelphia Electric Company; W. H. Hutt of the Federal Reserve Bank; H. B. Vincent of Day & Zimmerman; J. H. Tracy of the Electric Storage Battery Company. Attendance 102.

Pittsburgh.—March 8, 1921, Pittsburgh Chamber of Commerce Building. Two papers were presented as follows: "Electrical Features of Recent 100,000-H. P. Power Development at Niagara Falls" by Mr. J. Allen Johnson, Electrical Engineer of The Niagara Falls Power Company; "Salient Features of 32,500 Kv-a. Generator Design" by Mr. F. D. Newbury, Manager of Power Engineering Department, Westinghouse Elec. & Mfg. Co. Colored moving pictures by the Niagara Falls Power Company.

Pittsfield.—February 24, 1921. Subject: "Elements of the Automobile." Speaker: Dr. Rowland Rogers, Bray Studio, N. Y. Attendance 500.

March 3, 1921, Masonic Temple. Subject: "Instruments of the Orchestra." Speaker: Mr. John B. Taylor of the General Electric Company. Attendance 600.

Portland, Ore.—January 11, 1921, University Club. Subject: "The What and Why of Industrial Illumination." Speaker: Mr. O. L. Johnson. Refreshments were served after the meeting. Attendance 70.

Rochester.—February 25, 1921. Subject: "The Engineering Application of Electricity to the Automobile." Speaker: "Mr. G. R. Fessenden, Service Engineer of the Northeast Electric Company. Attendance 84.

San Francisco.—January 28, 1921, Engineers Club. Subject: "Pitt River Power Development of the Pacific Gas and Electric Company." Speaker: Mr. A. H. Markquart. Attendance 195.

Schenectady.—February 18, 1921, Edison Club Hall. Subject: "Making the Desert Bloom." Speaker: Mr. C. J. Blanchard, Statistician, U. S. Reclamation Service, Department of the Interior. Attendance 220.

March 4, 1921, Edison Club Hall. Subject: "The Economic Situation in Europe." Speaker: Mr. D. B. Rushmore of the General Electric Company. Attendance 220.

Seattle.—January 20, 1921, Bagley Hall, University of Washington. Joint meeting with the American Chemical Society and the Sigma Xi Fraternity. Subject: "The Chemistry of the Stars." Speaker: Dr. J. S. Plaskett, Director of the Canadian Government Astro-Physical Observatory at Victoria, B. C. Attendance 225.

February 14, 1921, Arctic Club Assembly. Subject: "Giving the Kilowatt a Show, Regardless of Whether the Kilowatt is used for Power Telephone or Radio Purposes." Speaker: Mr. R. W. Clark. Attendance 36.

Spokane.—January 7, 1921, Davenport Hotel. Illustrated lecture on "What and Why of Industrial Illumination." Attendance 67.

February 4, 1921, Davenport Hotel. A four reel motion picture on the subject "Coal is King" was shown and was followed by a discussion of the practises followed in the use of coal. Attendance 61.

Syracuse.—February 11, 1921, Technology Club. Subjects: "The Electric Furnace" by Mr. C. J. Rammling; "Brass Furnaces" by Mr. H. H. Plank. Attendance 62.

Toronto.—February 18, 1921. Joint meeting with Hamilton Branch of Engineering Institute of Canada. Subject: "Progress and Achievements in Radio Engineering." Speaker: Mr. Samuel M. Kintner. Attendance 180.

March 3, 1921. Joint meeting with the Toronto Branch of the Engineering Institute of Canada. Subject: "Ice Formation and Prevention." Speaker: Mr. John Murphy. Attendance 180.

Urbana.—February 25, 1921, Engg. Lecture Room, University of Illinois. Subject: "Rates and Rate Making." Speaker: Mr. Donald A. Henry. A film was also shown showing the process of manufacture of leather belting and another on the manufacture of storage batteries. Attendance 70.

Utah.—March 4, 1921, Commercial Club. Subject: "Electric Arc Welding." Speaker: Mr. E. Bachman of the General Electric Company. Attendance 65.

Vancouver.—February 4, 1921. Subject: "Electrification of Railroads." Speaker: Mr. F. W. McNeil. Attendance 24.

Washington, D. C.—March 8, 1921, Cosmos Club Hall. Subject: "Industrial Electrical Heating." Speaker: Mr. P. A. Meyer of the General Electric Company. Attendance 115.

Worcester.—February 25, 1921, Worcester Polytechnic Institute. Subject: "The St. Lawrence Project." Speaker: Mr. Henry I. Harriman, President, New England Power Company. Attendance 125.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—February 3, 1921. Subject: "Hydroelectric Development." Speaker: Mr. J. D. Hurlbert. Attendance 26.

February 17, 1921. Subject: "The Methods of Hydro-

electric Development." Speaker: Mr. W. E. Mitchell of the Alabama Powers Company. Attendance 41.

University of Arkansas.—March 1, 1921. Subjects: "Conservation of Natural Resources" by Professor B. N. Wilson; "Electrical Apparatus Development During 1920" by Mr. H. B. Curtis; "Electrification of the Prussian Railways in Silesia" by Mr. Jack Thompson. Attendance 15.

Armour Institute of Technology.—February 18, 1921. Subjects: "Motion Picture Projectors" by Mr. Robert P. Burns; "Salesmanship" by Mr. Fletcher E. Hayden. Attendance 24.

Brooklyn Polytechnic Institute.—February 11, 1921. Subject: "Radio Engineering as a Profession." Speaker: Mr. Pierre H. Boucheron. Attendance 17.

February 24, 1921. Subject: "The Story of the Telephone." Speaker: Professor W. H. Freedman. Attendance 21.

University of California.—February 9, 1921. Subject: "Vacuum Tubes." Speaker: Mr. B. F. McNamee of the Moorhead Laboratories. Attendance 48.

February 23, 1921. Subject: "Illumination." Speaker: Mr. Prussia. Attendance 22.

California Institute of Technology.—February 24, 1921. Joint meeting with Chemistry Club and local Branch of A. S. M. E. Subject: "Electric Precipitation." Speaker: Mr. E. R. Wolcott of the Western Precipitation Company. Attendance 54.

Clemson Agricultural College.—February 18, 1921. Subject: "Mechanical Application of Electrical Motors." "Application in the Machine Shop" by W. W. Watkins; "Application to the Lumber Industry" by J. D. Salley; "Application to the Textile Industry" by W. M. Clatworthy; "Current Events" by F. D. Thomas. Attendance 25.

University of Colorado.—March 3, 1921. Subject: "Electrification of Steam Railroads." Speaker: Prof. M. S. Coover. Attendance 36.

Drexel Institute.—February 18, 1921. Business meeting followed by joint technical session with local Branch of A. S. C. E. Subjects: "Electrical Instruments" (lantern slides) by Wm. B. Creagmile (local Branch A. I. E. E.) "Clean Streets in Philadelphia" by James Follin (local Branch A. S. C. E.). Attendance 25.

Georgia School of Technology.—February 17, 1921. Subject: "Summer Work and Graduate Student Work." Speakers: Mr. L. E. Anderson, Westinghouse; Mr. H. E. Watkins, A. T. & T. Co.; Mr. C. C. Welchel, Westinghouse; Mr. J. O. Shepherd, G. E. Co. Attendance 27.

University of Iowa.—February 7, 1921. Election of officers as follows: Chairman, Charles Krause; Vice-Chairman, T. Varbedian; Secretary-Treasurer, A. P. Beyers. Attendance 34.

February 15, 1921. Subjects: "Course of Training in the U. S. Navy Steam Engineering School" by Mr. E. M. Apfel; "Cylinder Grinding" by Mr. I. MacDaniel; "Temperature Relays" by E. Paintin. Attendance 36.

Iowa State College.—February 16, 1921. Subjects: "Telephone Transmission" by Mr. G. H. Gray, Omaha Telephone Company; "Outside Plant Construction" by Mr. R. H. Fair, also of the Omaha Telephone Company. Attendance 35.

March 2, 1921. Subject: "Automatic Railway Substations." Speaker: Mr. John Drabelle, Iowa Railway and Light Company. Attendance 98.

University of Kansas.—February 9, 1921. Subject: "Problem of Finance." Speaker: Mr. J. T. Skinner, Manager of Kansas Electric Utilities Co. Attendance 18.

February 24, 1921. Subject: "The Utah Apex Mining Co., Bingham Cannon, Utah." Speaker: Mr. Harry Appleby '22. Refreshments were served. Attendance 91.

March 1, 1921. Subject: "Telephone Machine Switching." Speaker: Mr. W. E. Wickenden, Western Electric Company. Attendance 50.

Kansas State Agricultural College.—February 24, 1921. Election of officers as follows: Chairman, William Bucklee; Secretary, H. J. Staib; Treasurer, J. J. Seright. Subjects: "Home Lighting in the City of Manhattan" by Mr. W. C. Mars and "Electrification of Small Towns" by Professor C. E. Reed. Attendance 83.

March 3, 1921. Subjects: "Selling Your Services" by Mr. J. E. Byers; "The 'Three-Phase' Student" by Mr. Earl Thomas; "Illumination" by Mr. C. L. Zimmerman. Attendance 89.

University of Kentucky.—February 14, 1921. Subjects: "Regulation of Frequencies for Measurement Purposes" (A. I. E. E. February JOURNAL); "Progress of the Use of Electricity in the Industrial and Domestic Fields" (A. I. E. E. February JOURNAL); "Adjustable Laboratory Rheostats" (February *Electrical Engineer*). Attendance 22.

University of Maine.—February 16, 1921. Talks were given by Mr. W. S. Stevenson on summer work with the Westinghouse Company and Mr. J. Bernard on his work with the U. S. Air Mail Service. Attendance 26.

Massachusetts Institute of Technology.—February 17, 1921. Subject: "Labor in Production." Speaker: Mr. Mathew Poroshy of the Holtzer-Cabot Co. Refreshments were served. Attendance 54.

February 24, 1921. Subject: "Cable Construction." Speaker: Mr. E. W. Davis of the Simplex Wire and Cable Co. Refreshments were served. Attendance 65.

University of Michigan.—March 8, 1921. A talk was given by Mr. R. C. Bergrall, senior electrical engineer on power plants, relating especially to the problem of the electrification of a 450 mile stretch of road in Montana. Attendance 20.

School of Engineering of Milwaukee.—February 18, 1921. Subjects: "Engineering Reports from the Standpoint of the Practising Engineer" by Professor F. A. Kartak; "Relation of English to Engineering Reports" by Professor F. G. Fox; "Curves and Charts" by Professor Yeaton. Attendance 143.

University of Minnesota.—February 21, 1921. Subjects: "Radio-Telephony" by Mr. C. M. Jansky; "High-Frequency Phenomena" by Mr. E. C. Manderfeld and demonstration by Messrs. Manderfeld and Wessale. Attendance 85.

University of Missouri.—February 21, 1921. Subjects: "Inventory Methods for Valuation Purposes" by Mr. J. S. Palmer; "Valuation of Public Utilities" by Mr. O. J. Rotty; "Course of Training offered by the Century Electric Company" by Mr. O. S. Imes. Several reels of General Electric movies were also shown. Attendance 30.

March 8, 1921. Subject: "Transmission of Power at 220,000 Volts" by Mr. W. C. Austry. General Electric film "Queen of the Waves" was shown. Attendance 42.

Montana State College.—February 18, 1921. Moving picture film "King of the Rails" was shown. Attendance 359.

University of Notre Dame.—March 7, 1921. Subjects: "Report of the Berrien Springs Power Plant" by Mr. C. Tarnava, and "Report of the Elkhart Power Plant" by Mr. F. Miles. Attendance 18.

Oklahoma A. & M. College.—February 15, 1921. Subjects: "Automatic Stations" by Mr. M. C. Courtney and "A Summer's Work with the Oklahoma Railway Company" by Mr. Oral Baker. Attendance 19.

University of Pennsylvania.—February 11, 1921. Subject: "Electric Ship Propulsion" by Mr. K. McIlwain. Attendance 41.

February 18, 1921. Subject: "Electric Locomotives." Speaker: Mr. H. Peters. Attendance 41.

February 25, 1921. Subject: "Electric Starting Systems for Automobiles." Speaker: Mr. R. W. Robinson. Attendance 41.

University of Pittsburgh.—March 1, 1921. Subjects: "The Duquesne Light Company"—a description of its power plant at Bruno's Island, together with some features of its distribution system, by Mr. John J. Finnerty; "Commercial

Tests of Induction Motors at the W. E. & M. Co." by Mr. H. K. Aalborg. Attendance 21.

March 8, 1921. Subject: "The Vector Solution of an A-C. Single-Phase Distribution Line, Containing Uniformly Distributed Impedance and Leakage Resistance, but Having Zero Distributed Capacity"—a special case of the general distribution line problem applied to a-c. railroad signaling. Speaker: Mr. C. B. Bennett. Attendance 26.

Rensselaer Polytechnic Institute.—February 22, 1921. General Subject: "Recent Advances in Science and Engineering." Speakers: Mr. W. Byrne on "The Laws of Probability as Applied to the Choosing of the Number of Selectors for an Automatic Telephone Exchange"; Mr. H. Mimmo on "The Brown Tube"; Dr. Sebast contrasted the new Westinghouse oscillograph with the old type; Dr. Robb on "The Proposed Superpower Development;" Dr. Hunter on "The New Reported Method for Obtaining Aluminum from Ordinary Clay"; Professor Eldred on "The Proposed 220-Kilovolt Transmission Line in California"; Professor Williams on "The Recent Advances in the Telephone Game." Attendance 30.

Syracuse University.—February 18, 1921. Subject: "Stray Currents from Electric Railways." Speaker: Mr. Verdin. Attendance 13.

University of Texas.—February 14, 1921. Subjects: "Lightning Arresters" by Mr. Ray Barnard; "Railroad Block Signaling" by Mr. J. A. Jaccard; "Fuses" by Mr. B. A. Crocker; "Relays" by Mr. S. W. Marchall; "Protective Devices" by Mr. C. B. Lain. Attendance 25.

Virginia Military Institute.—February 12, 1921. Subjects: "Proposed Water-Power Development on the St. Lawrence" (material taken from article of similar nature in the *Electrical World* of February 8, 1921) Mr. Frederick P. Wilmer; "The Engineer and His Service" by F. F. Vaughan. Attendance 41.

February 24, 1921. Joint meeting of all departments of engineering. Address by Mr. Homer I. Ferguson, President of the Newport News Shipbuilding and Dry Dock Company. The talk was general in its nature but was of particular interest to those students about to enter the engineering field. Attendance 500.

University of Washington.—February 3, 1921. Subject "Making the Telephone Talk." Speaker: Mr. Scott, Chief Engineer of the City Telephone Company. Attendance 20.

State College of Washington.—February 25, 1921. Subject: "The Uses of the Vacuum Tube in Radio Work." Speaker: Dean H. V. Carpenter. Attendance 38.

West Virginia University.—February 21, 1921. Subjects: "The Engineering Profession Fifty Years Hence" by Mr. H. S. Shinn; "The Corona Voltmeter" by Mr. H. Chandler; "Welding Mild Steel" by Mr. R. L. Sheffer. Attendance 14.

Yale University.—March 8, 1921. Subject: "Water-Power Development." Speaker: Mr. Calvert Townley. Attendance 78.

March 11, 1921. Subject: "Industrial Illumination." Speaker: Mr. L. I. Edgerly. Attendance 60.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

SERVICES AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

CHIEF DRAFTSMAN, experienced in air compressors. Must understand the theory of compressed air and be able to design. Steam pump experience will be considered. Location Illinois. X-90.

SALES ENGINEER with technical education or Extensive practical experience with Alternating current Motors by well established manufacturer located west of the Mississippi River. Correspondence confidential. Give full partiuclars. X-216.

INSTRUCTOR in Electrical Engineering. Knowledge of modern telephone practise and theory important but not essential. Location Ohio. X-237.

TELEPHONE ENGINEERS with sufficient telephone training to handle central office engineering work. X-239.

MANUFACTURER of Power and Heating Apparatus requires services of Mechanical Engineer to act as assistant director of experimental test and development. Ability to lay out and direct work of employees in this Department is of more importance than ability to carry out processes personally. Executive ability, a clear knowledge of mechanics and usual shop practises, experience in development work along similar lines and persistence for overcoming difficulties, are necessary qualifications for this position. First letter should state age, training, experience, present connection, salary desired and facts concerning personality and mechanical and executive ability. X-244.

ELECTRICAL ENGINEER to manage branch office located in central New York. Want a man familiar and experienced in business of an electrical contractor, and preference would be given to a man who has been engaged in this business himself. X-256.

ENGINEER to take charge of plant on brass sheets, rods and tubes. Must be good plant executive, who is familiar with management of such a plant, and must have sufficient technical knowledge of metallurgy to look after his own plant properly. X-259.

CAPABLE MASTER MECHANIC for plant consisting of 5 General Electric 500-kw. turbo-generators, with 500-kw. motor generator sets for railway and corresponding boiler plant and condensing equipment. Should like to get man that has had experience in such work, but principal quality is

to be first class machinist, who can show mechanics how to do accurate repair work and at the same time has experience enough to know when repairs, should be made to machinery in question, before it gets in bad condition. Also have in connection with plant small machine shop, a lathe, 2 drill presses, grindstones, pipe cutting machine, and emery wheel; but expect to increase machinery in near future by a shaper and another lathe, so we can do nearly any kind of repair work ourselves. Prefer man who can speak Spanish language. Location Mexico. X-264.

FIRM OF ELECTRICAL CONTRACTORS with record of 10 years of increasing and profitable business, because of increased burden on existing members, desires to secure young man with electrical training and some practical experience,as partner or associate, to become actively interested and grow with the business. Nominal investment to secure interest and permanency will be required. Good profit on investment plus adequate salary to right man. This is opportunity for some one to enter a successful business and have a real voice in its conduct. Main question is to secure man whose age, training, experience and personality fit in with present partners. Location New York City. X-266.

INSTRUCTORS, two, in Electrical Engineering Department. Location Southern America. X-267.

ASSISTANT PROFESSORS, two, in Electrical Engineering Department. Location Southern America. X-268.

ENGINEER experienced in microscopy, photography, physics, and chemistry for research work in laboratory of large rubber company. Location New York City. X-269.

ENGINEER to sell propellers and accessories to boat builders, manufacturers of marine engines, dealers and others, propellers and bronze castings for ships; also small electric generators. Prefer a man about thirty years old as he will be on the road a great deal of the time. Previous selling experience essential. Splendid opening with chance for advancement and a permanent position. X-290.

CAPABLE ENGINEER to take charge of Shanghai office. Desire partner who will invest ten or twenty thousand dollars fair basis, good salary and profits of business, totaling last year four hundred thousand dollars order from twenty sole agencies. China representatives finance any orders. X-142.

MEN AVAILABLE

MECHANICAL AND ELECTRICAL ENGINEER, graduate in 1910; broad experience in design and supervision of construction of power plant and industrial building, including electrical, mechanical, steel and concrete equipments Stone and Webster experience. Connection with consulting engineering concern is most desirable. Starting salary $4000 in New York. E-2585.

ELECTRICAL ENGINEER, age 36; ten years experience in power station design, construction operation and industrial engineering. Assoc. A. I. E. E. Extensive purchasing and executive experience. Desirous of entering engineering sales field or executive position. Salary $3500-5000. Available at once. E-2586.

TECHNICAL GRADUATE, 1918; single. Has had experience in test, design and commercial departments of large electrical manufacturer. Would like position with consulting engineering firm, construction concern, or power company. Would consider going to Philippine Islands. Available April 1st. E-2587.

PARTNERSHIP CONCERN having comprehensive knowledge of eastern territory and requiremens of the field and extensive clientele, desires exclusive representation for high grade article, preferably mechanical devices, such as commodity handling apparatus. Location New York City. E-2588.

ELECTRICAL ENGINEER, technical graduate, experienced in design, construction and maintenance, desires position as electrical engineer for industrial concern or supervising engineer on construction. Age 30; married. Salary expected $3600. Assoc. A. I. E. E. E-2589.

GRADUATE ELECTRICAL ENGINEER, age 27; married. Three years good practical experience, power house, sub-station and transmission line. Assistant construction engineer. Not afraid of hard work. Would like permanent position with bright future. Kind of work or location optional. E-2590.

ELECTRICAL ENGINEER, recent graduate of University of Michigan; age 25; single. Desires position affording opportunity for advancement. Would consider work in foreign fields, especially South American or Panama. Available immediately. E-2591.

ELECTRICAL ENGINEER. Eleven years experience in manufacture and sale of automobile electrical equipment, storage batteries, train lighting and welding machinery, desires position in charge of development or sale of electrical machinery or control devices. E-2592.

TESTING ENGINEER, B. S. degree, desires position with consulting engineer or manufacturing company in vicinity of Philadelphia. Five years experience in electrical, mechanical and materials testing. Assoc. A. I. E. E. Age 26. E-2593.

SALES ENGINEER desirous of operating several high grade nonconflicting accounts in central and western New York State territory. Several years successful commercial and professional engineering experience. E-2594.

ELECTRICAL SUPERINTENDENT, technical training, twelve years experience central stations, industrial plants, construction and maintenance, familiar with electrical contracting and its requirements, transmission systems up to 110,000 volts, electric precipitators, cranes, locomotives, turbines, chlorine cells, supplies, automatic control apparatus, electric welding, can design and lay out electrical equipment for industrial plants, can handle any number of men and work demanding executive and organizing ability, energetic tactful, age 32; married. Member of A. I. E. E.; A. I. and S. E., E-2595.

GRADUATE ENGINEER, 6½ years industrial plant maintenance and construction experience on design and field inspection of erection; buildings conveyers, heating and piping systems, property surveys, sewers and trackwork. Excellent references. E-2596.

SALES ENGINEER, desirous of taking on number of high grade non-interfering accounts for operation in vicinity of New York and for export to foreign countries. Fifteen years experience in sales engineering work. Successfully introduces a number of products and with existing organization in position to quickly penetrate trade with several new lines. E-2597.

GRADUATE ELECTRICAL ENGINEER; age 31; married. Ten years experience in design selection and ordering of materials, construction and operation of electrical power and industrial equipment of large installations. Seeks position offering great enough opportunities to warrant permanent residence. Available on short notice. Location preferred East Coast. Present salary $3000. Excellent references. E-2598.

PURCHASING AGENT, age 34. Five years experience in heavy electrical equipment supplies. Available immediately. E-2599.

GRADUATE ELECTRICAL ENGINEER, age 29. Two years General Electric test; one and one half years construction work; two years teaching in large university; one year in army. Would like to work for large public utility in a place where he can study operation and management of business. Western location perferred. E-2600.

GRADUATE ENGINEER, B. S. in M. E. 1919. Two years experience in d-c. and high voltage a-c. railroad electrification. Desire position with responsibility for advancement. Minimum salary considered $2000. Pacific coast preferred, but will go anywhere. E-2601.

ELECTRICAL MECHANICAL ENGINEER, age 24; desires position on construction or maintenance work as assistant chief or where opportunity for executive position is good. Foreign or domestic service. One year civil engineering; four years installation, manufacture and maintenance; one year safety engineer. Present time power plant engineer. Salary $2500. E-2602.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER. Five years experience in power plant layouts, installation, operation and maintenance mechanical and electrical apparatus. Age 27; married. Present salary $4000. Familiar with contracts and estimating. Desires position with consulting engineer; any other good offer considered. Location Louisiana, Tennessee, Oklahoma, Texas, Missouri, etc. E-2603.

EXECUTIVE. Engineering and business experience; Univeristy graduate; engineering and law; age 34. E-2604.

TECHNICAL GRADUATE with factory, construction, operating and commercial experience and training available on not less than two months notice as general superintendent or assistant to general manager of power company. Health unusually good, possesses strong reserve of physical and nervous energy. Good general business knowledge. E-2605.

INSPECTING SPECIALIST for railway cars and their equipment. Thoroughly acquainted with modern G. E. and Westinghouse apparatus for the single car, locomotive or multiple unit train of d-c. or a-c. types. Understands in detail central station apparatus from the condenser intake to transmission lines and its substations. E-2606.

ELECTRICAL ENGINEER, technical graduate, age 35; single. Two years experience small power plants and line work; ten years broad experience marine work, drafting, wiring, supervision installation apparatus, desires position offering broad opportunity for advancement in the vicinity New York or Philadelphia. Available short notice. E-2607.

ELECTRICAL AND MECHANICAL ENGINEER, thoroughly experienced, wants responsible position in New York. Executive, manager, superintendent, expert. Practised in manufacturing, development, maintenance and consulting. Large and small machines and appliances. Modern system. Directing large numbers male and female employees. B. S. and E. E. Univeristy of Pa. E-2608.

MECHANICAL AND ELECTRICAL ENGINEER. Technical training; age 38; married; with sixteen years experience in design, construction and operation of power, substation and distribution all tensions. Actually chief engineer large South American street railway light power concern. Thorough knowledge French, Portugese. Desires a change. South America or Southern Europe. E-2609.

ELECTRICAL-MECHANICAL ENGINEER age 42; married; university graduate. Fifteen years experience in this country and abroad in design, and construction of power and substations, electrical machinery and equipment and industrial engineering. Thoroughly conversant with a-c. and d-c. systems of distribution; high and low tension. E-2610.

GRADUATE ELECTRICAL ENGINEER. Twelve years experience designing, constructing, operating and appraising electrical properties, industrial plants, public utilities, etc. Position desired with progressive firm in North Central States. Available on short notice. E-2611.

ELECTRICAL ENGINEER, Member A. I. E. E. and A. S. M. E. age 41. Fifteen years experience in general industrial and, power plant engineering. Position preferred in Boston or New York City. Available in 30 days. E-2612.

FOREIGN REPRESENTATIVE, graduate electrical engineer, age 35; native of a Balkan State; working knowledge of French, Russian and most Slavic languages; four years experience with large western public service corporation; past three years in U. S. Government service. Further information gladly furnished. E-2613.

ELECTRICAL ENGINEER, graduate; age 33; married. Just completed installation of electrical equipment in one of the most up-to-date steel mills in the country. Can handle this sort of work for mills or factories in the most economical and efficient manner. Expert on reducing power bills. E-2614.

ELECTRICAL ENGINEER, technical graduate; age 27. Experienced in design of generating and substations, distribution systems, etc. Familiar with textile industry and modern production methods. G. E. test, training for sales engineer. Desires position in or near New England. E-2615.

EXPERIENCED SALES ENGINEER would consider change to position where compensation is commensurate with results and opportunity for growth exists. Familiar with central station, railway and mining equipment. E-2616.

GRADUATE ELECTRICAL ENGINEER, age 29; married. At present in transportation department of large street railway company, wishes to make change. Five years experience electric street railway maintenance and operation; nine months sales engineering experience with well known company, manufacturing electric wires and cables. Desires permanent position in sales engineering with company manufacturing electric railway supplies or other electrical machinery or devices. Would also consider permanent position in traffic analysis work or similar work allied to electric railway industry. New York City or middle Atlantic states preferred. References furnished upon application. Available on two weeks notice. Minimum salary $3000. E-2617.

GRADUATE ENGINEER, four years electrical experience in testing, laboratory, electrical construction of power houses, substation and transmission lines. Interested in generation and distribution of electric power. Familiar with design work and engineering economic studies. Age 29; single; American; protestant. Salary $2800. E-2618.

ELECTRICAL ENGINEER, age 25. Will graduate from college in June. Have also completed in I. C. S. course. Have been as assistant instructor while in college. Have had experience in construction work. E-2619.

INDUSTRIAL PLANT ELECTRICAL ENGINEER graduate; age 30; speaks Spanish. Nine years experience in design, selection and ordering of materials, construction and operation of electrical power and industrial equipment of large installations. Prefer proposition based on results attained. Seeks position offering great enough opportunities to warrant permanent residence. E-2620.

PRODUCTION OR SALES ENGINEER, age 27; married. Mechanical Electrical graduate with good commercial training. Three years experience production and engineering sales. Work covered; engineering correspondence, specifications; office methods; routing and scheduling machine work, drop hammers, crank and toggle presses, cost determination. Desire position in production or engineering sales. References furnished. E-2621.

ENGINEER EXECUTIVE, age 42. Twenty years experience in engineering, construction and maintenance of large public utility. College graduate. Desires connection with industrial or financial concern offering good opportunities. Large experience in organization, production, appraisal, accounting and labor problems. Present salary $6000. E-2622.

ELECTRIC DISTRIBUTION ENGINEER, age 29; technical graduate. Five years experience as superintendent of electric distribution department of large public utility serving a population of approximately 100,000. Location desired New York State or vicinity. Best of references. Available on short notice. E-2623.

TECHNICAL GRADUATE, age 26; married. Five years experience drafting, marine work, wiring, electric meters, machine shop, electrical testing, Assoc. A. I. E. E. Desires position with chance for advancement. Available immediately. E-2624.

ELECTRICAL ENGINEER, technical graduate. Eight years experience covering hydroelectric and steam power plant and substation operation, maintenance, design and construction; extensive testing and repairing all electrical apparatus used; acceptance tests on new stations; overhead and underground distribution and street lighting systems. Ex-Captain U. S. Army. Desires position of responsibility with good future with central station organization or firm of consulting engineers. Pacific coast preferred. Best references; available short notice. E-2625.

ELECTRICAL ENGINEER, college graduate 1917; has had experience in telephone work, both automatic and manual; general plant maintenance; design and layout of power houses and sub-stations; and in general electrical research work. Desires something permanent in any locality. E-2626.

ELECTRICAL MECHANICAL ENGINEER, age 27; technical graduate. Four years experience in large and small factories. Good executive. Desires position with a growing concern. Would consider engineering sales proposition. Location immaterial. E-2627.

MECHANICAL ELECTRICAL ENGINEER seeking new connection, would like to hear from responsible parties. Expert on operation of industrial plants; capable executive; valuable purchasing experience. Technical education; sixteen years practical experience. Age 40; married; good health. E-2628.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Leo Arany, Room 201 Parkway Bldg., Broad & Cherry Streets, Philadelphia, Pa.

2.—De Los De Tar, 411 East 15th Street. Kansas City, Mo.

3 —H. S. Logan, 215 15th Street, Seattle, Wash.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MARCH 11, 1921

ALBRIGHT, JOHN J., Jr., Electrical Engineer, Niagara, Lockport & Ontario Power Co., Syracuse, N. Y.

ALLEN, ASA EDWARD, Engineer, Southwest General Electric Co., Interurban Bldg., Dallas, Texas.

ANDREWS, RALPH J., Sales Engineer, Sangamo Electric Co., Jackson, Mich.

ASCHENBRENER, RUDOLPH A., Power Salesman, The Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

*ASHENDEN, HARRY B., Student Engineer, Cutler-Hammer Mfg. Co.; res., Y. M. C. A., Milwaukee, Wis.

ASPINWALL, GEORGE L., Vice President, Atlantic Radio Co., 88 Broad St., Boston, Mass.

BAILEY, GEORGE L., Electrician, *New York World* 63 Park Row, New York, N. Y.

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BALDWIN, BENJAMIN W., Salesman, St. Paul Electric Co.; res., 2258 Commonwealth Ave., St. Paul, Minn.

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BEARSE, EDWIN W., Electrical Engineer, General Electric Co., 3rd National Bank Bldg., Atlanta, Ga.

BEAVERS, FRANKLIN J., Engineer, Electrical Dept., Gary Heat, Light & Water Co.; res., 801 Jefferson St., Gary, Ind.

BELL, FREDERICK N., Engineer, Control Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1001 Franklin Ave., Wilkinsburg, Pa.

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INGRAM, CLYDE O., Chief Operator, The B. F. Goodrich Co., Akron, Ohio.

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TRANSFERRED TO GRADE OF FELLOW MARCH 11, 1921

RIDDILE, J. S., Manager of Power, Laurentide Power Co., Ltd., Grand Mere, Quebec.

TRANSFERRED TO GRADE OF MEMBER MARCH 11, 1921

ANDERSON, OSCAR V., Superintendent, Distribution Dept., Toronto & Niagara Power Co. and Toronto Railway Co., Toronto, Ontario.

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SEABURY, RICHARD W., President, Boonton Rubber Mfg. Co., Boonton, N. J.

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RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held February 11 and March 4, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

YOKURA, MORINOSUKE, Engineer-Captain Chief of Electrical Engineering Bureau, Imperial Japanese Navy, Tokyo, Japan.

To Grade of Member

AMOS, WALTER L., Electrical Engineer, Engineering Dept., Hydro-Electric Power Commission of Ontario, Toronto, Ont.

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Synchronous Motors for Ship Propulsion

BY E. S. HENNINGSEN
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SINCE the inception and development of the idea of electric ship propulsion, the question of the possibility of using synchronous motors for such service has often been raised. Such a motor could be designed for unity power factor with a resulting saving in cost, weight, and efficiency, of both motor and generator. So far as mechanical design was concerned, the answer was, of course, that the same substantial mechanical features could be obtained with a synchronous motor as with an induction motor. In addition, the synchronous motor would have greater clearance between rotor and stator and repairs could be more easily made since it would not be necessary to remove the rotor to replace either field or armature coils. The question, therefore, was whether or not satisfactory electrical characteristics could be obtained with this type of motor. The affirmative answer to this question is attested to by the fact that the S. S. *Cuba*, a fast passenger and express boat belonging to the Miami Steamship Company, and the first vessel of any kind to be propelled by a synchronous motor, has been in successful operation since November 1920, and five more equipments are under construction. Four of these are to drive cutters being built for the U. S. S. Coast Guard Service and one for a fruit steamer.

The first consideration in the problem was to determine as accurately as possible what the torque requirements were, first under normal operation, and second, during reversal of the propeller. The only point in question under normal operation is the margin in break-out capacity that is required to keep the motor in step during rough weather or when the ship is making a turn. From the limited data available on single-screw ships, it appears that the torque imposed on the propeller, due to the pitching of the ship in rough weather, varies between zero and about 175 per cent of the average. The period of this variation in torque is about seven seconds. However, this requirement is not peculiar to the synchronous motor drive, since it is equally necessary to meet this condition with any form of electric drive. Since the break-out capacity depends upon the ratio of no-load ampere turns to synchronous impedance ampere turns and also upon the amount of field excitation that can be carried on both motor and generator, sufficient break-out torque is simply a question of proper design.

The torque required to reverse the propeller under full speed conditions has been accurately determined for battleships by the Navy Department, and is illustrated in Fig. 1 for the U. S. S. *Delaware*.[1] This curve, which assumes that the ship continues ahead at full speed, shows that when the driving torque is reduced to zero, the propeller drops to the no-slip speed which is 76 per cent of its full speed. To

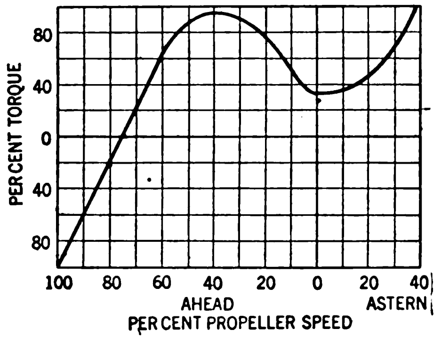

FIG. 1—CURVE OF TORQUE REQUIRED TO REVERSE THE PROPELLERS OF THE U. S. S. *Delaware*

bring the propeller to rest against the action of the water requires a constantly increasing torque until at about one-half of the no-slip speed, the maximum braking torque is reached. This value is about 95 per cent of full torque. Below the speed the required torque falls off and at zero propeller speed is about 33 per cent. One hundred per cent of normal torque is required to drive the propeller at 38 per cent speed backwards. These values will, of course, be somewhat lower due to the retardation of the ship during the time required for switching and reversing. No such accurate curve is at present available on a single-screw ship, but tests on several such ships indicate

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

1. From an article by Lieut. S. M. Robinson, U. S. N., *Journal American Society Naval Engineers*, February 1916.

that the torque required to reverse the propeller is materially less than that shown in Fig. 1. It is, therefore, safe to assume that this curve represents the maximum torque requirements that must be met during reversal.

In land practise, motors are usually operated from a constant potential and constant frequency system. For ship drive, since the main power circuit comprises only the generator and the motor, it is neither necessary nor economical to design for

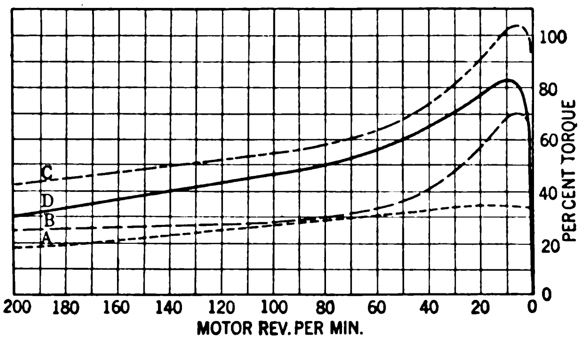

FIG. 2—BRAKING TORQUE TEST—GENERATOR AND SYNCHRONOUS MOTOR CONNECTED TOGETHER WITH OPPOSITE PHASE ROTATION

Test *A*—Field on Generator. Motor field short-circuited.
Test *B*—Field on motor. Generator field short-circuited.
Test *D*—Field on both motor and generator.
Curve *C*—Sum of curves *A* and *B*.

either constant potential or constant periodicity during the operation of reversing. In other words, both motor and generator may be overexcited for brief periods and advantage may be taken of the fact that the generator's speed can be reduced until the motor has been synchronized and the two units then brought up to speed together. Based on these facts a number of methods of reversal were suggested and tested out on an equipment consisting of the following machines: A 375-kv-a. generator, driven by a 3600-rev. per min. turbine, was used to supply power to a 36-pole, 275-h. p. synchronous motor. The propeller was represented by a 200-kw. direct-current generator mounted on the same shaft with the motor. By varying the field excitation of the motor-driven exciter to which the d-c. generator was connected, the load on the synchronous motor could be reversed and varied rapidly enough to approximate very closely the propeller torque curve of Fig. 1.

The results of some of the tests made on this equipment may be briefly summarized as follows:

1. The first method to be tried out was to cut off the steam from the turbine, reverse the phase rotation between motor and generator, establish field excitation on both machines, allow the turbine to come to rest with the motor and then start up by admitting steam to the turbine, bringing the motor up in synchronism with the generator from zero speed. Although sufficient braking torque could be developed by this method, it was not found to be feasible because the amount of load that could be started was very small when the number of poles of the generator differed widely from those of the motor. On the particular motor and generator used in these tests, it was found that with normal full load field current on each, the motor could just be started with no-load on the d-c. generator. With 190 per cent of normal full load field current on each only 22½ per cent of normal load could be started. This method is also objectionable on account of the high temperatures that result when steam is admitted to the turbine at standstill.

2. The second suggestion was to reverse the phase rotation and establish both fields as before but allow the generator to drop to only one-fourth speed. The objection to this method was the excessive mechanical vibration that resulted when the motor was at standstill but still excited and the generator running (also excited) at one-quarter speed. In this connection it is interesting to note the test shown in Fig. 2. Curve *A* represents the torque developed by the amortisseur winding of the motor with normal excitation on the generator field and the motor field short-circuited. Curve *B* represents the torque developed by the motor functioning as a generator with normal excitation on the field and the armature leads connected to those of the generator. It was expected that with both fields normally excited, the resulting torque curve would be the sum of curve *A* and curve *B*, or curve *C*.

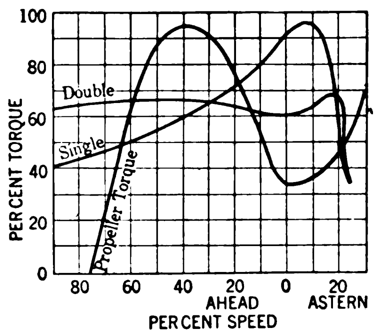

FIG. 3—COMPARISON OF THE TORQUE CURVES OF A SYNCHRONOUS MOTOR WITH SINGLE AND DOUBLE AMORTISSEUR WINDINGS

The generator was held at one quarter normal speed and had the same field excitation for each curve.

Instead, the resultant curve *D*, obtained from test, shows that due to interference of the two polyphase systems of opposite phase rotation, the resulting torque is only about 86 per cent of the sum of the separate torques.

3. The motor was then equipped with a double amortisseur winding to find out whether the advantage so gained would be worth the added mechanical difficulty. Fig. 3 shows the test curves obtained with both the single and double amortisseur windings. The generator was run at one quarter of full speed

and with the same field excitation for both curves. It will be noted that the double winding will give a slight gain in the time of stopping the propeller, but an almost equal loss in time to come up to speed

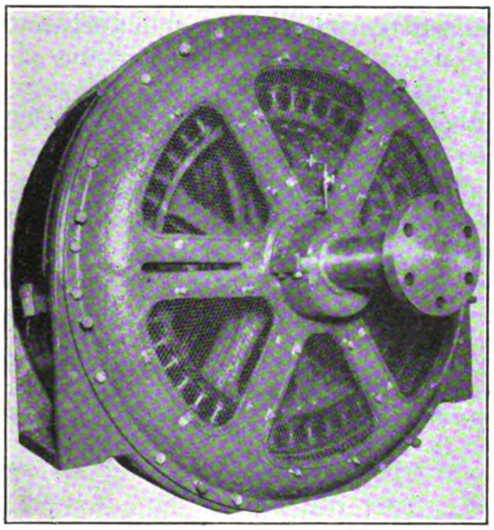

Fig. 4—Coupling End of 46-Pole, 2600-H. P., 50-Cycle, 130-Rev. per Min., Synchronous Motor for Ship Propulsion

in the opposite direction, hence practically no advantage will be obtained with the double winding.

4. It was found that with a given field excitation on both generator and motor, a 10 per cent greater maximum load could be carried before the motor would fall out of step when the load was varied between zero and a maximum in a seven-second period, than when the load was gradually applied. Also when the swinging load was increased somewhat and the motor fell out of step on the high swing it would pull back into synchronism on the low swing.

5. The tests showed that the two most satisfactory methods of accomplishing a full speed reversal of the propeller are as follows:

Method No. 1: (a) Throw the turbine speed governing mechanism to the quarter speed position; (b) reverse the phase rotation between motor and generator; (c) excite the motor field only, thus causing the motor to function as a generator and hence brake the propeller to zero speed; (d) energize the generator field and deenergize the motor field, thus causing the motor to come up to approximately one-fourth speed as an induction motor; (e) apply motor field to synchronize, and (f) bring up the turbine speed.

Method No. 2: (a) and (b) same as in Method No. 1, (c) establish field on the generator, thus causing the motor to come to rest and up to approximately one-quarter speed in the opposite direction by means of the amortisseur winding torque only; (d) apply motor field to synchronize, and (e) bring up the turbine speed.

Method No. 1 although requiring one more operation has the advantage that very much higher braking torque can be obtained from the generator characteristic than from the induction motor torque characteristic and also that it affords a means of keeping the propeller from rotating while the ship is still going ahead due to its momentum, a procedure which is not possible without complicated control when only the induction motor torque characteristic is used.

The construction of synchronous motors for ship drive is illustrated by Figs. 4 and 5. They differ in the following particulars from those designed for land practise: The diameter is smaller and the length correspondingly greater; they are of the end shield bearing type; the air gap clearance is somewhat greater; special precautions are taken to make the insulation moisture-proof; the amortisseur winding is so constructed that the poles may be removed without removing the rotor; jacking bolts are provided in the bearing housings for taking the weight of the rotor when it is desired to remove a bearing. In

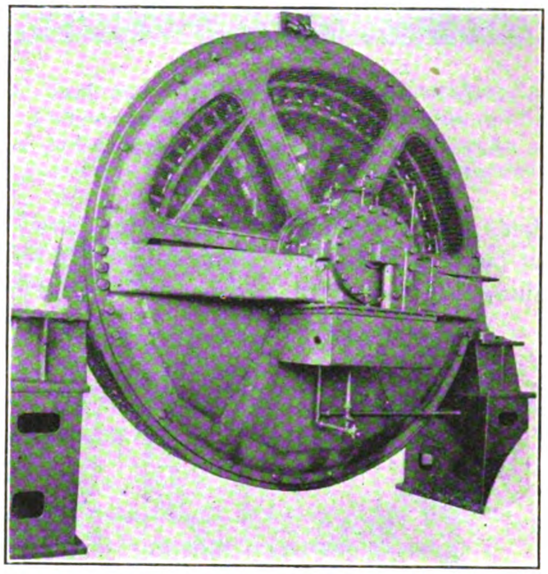

Fig. 5—Thrust Bearing End of 60-Pole, 3000-H. P., 50-Cycle, 100-Rev. per Min., Synchronous Motor for Ship Propulsion

order to facilitate temporary repairs, the armature winding has as large a number of circuits as the number of poles will permit. Then in case of a burn-out it is only necessary to cut out that particular circuit or circuits without having to install jumpers across the damaged section. Since the power to drive the propeller varies approximately as the cube of the speed, cutting out one circuit of a twelve-circuit winding, for instance, would mean a drop in speed of only a little more than 2½ per cent to keep the load on the other circuits as before.

The motor illustrated in Fig. 5 has the ship's main thrust bearing installed in the forward lower bearing bracket, the upper part of which is made in the form of a deep beam. Details of this spring thrust bear-

ing are shown in Fig. 6. Lubrication of the thrust bearing and horizontal bearings is furnished by an oil pump, driven from the main shaft and mounted in an oil tank bolted to the under side of the bearing

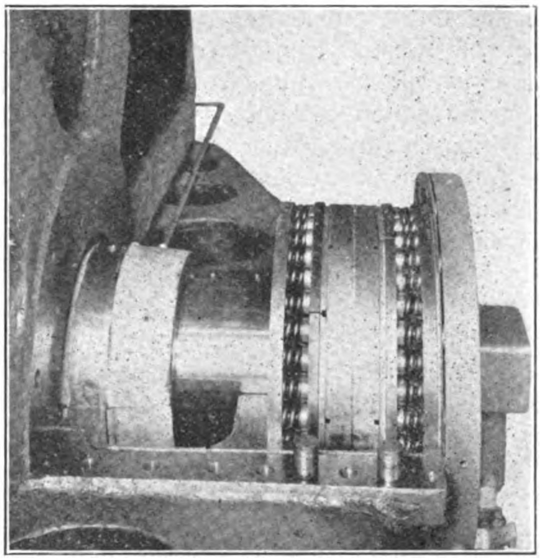

Fig. 6—3000-H. P., 50-Cycle, 100-Rev. per Min., Synchronous Motor for Ship Propulsion

With bearing caps removed to show one journal bearing and spring thrust bearings assembled in lower bearing bracket.

bracket. This particular design of the motor, thrust bearing, and oil system as a unit, contemplated installing the motor in a separate compartment as

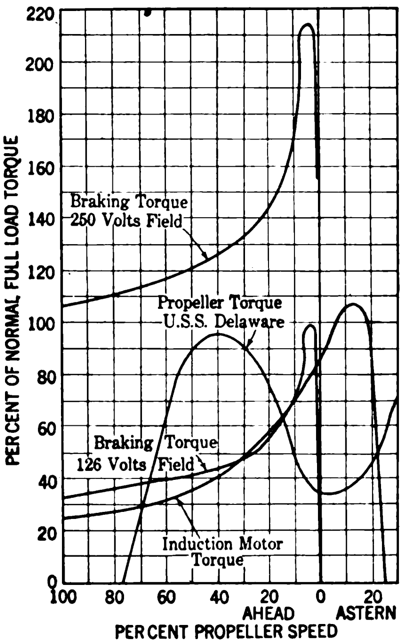

Fig. 7—Torque Characteristics—3000-H. P., 100-Rev. per Min., Synchronous Motor

far aft as possible and hence doing away with the usual long shaft alley. In such an installation a gravity feed oil system could be installed to be used in case of a failure of the direct-connected oil pump. With such low speeds as are employed, very little lubricating oil is required and a comparatively small gravity tank would supply oil until repairs could be made. With a motor such as shown in Fig. 4, the spring thrust bearing is mounted in a separate housing.

Fig. 7 shows the torque characteristics of an equipment consisting of a 3000-h. p., 100-rev. per min. synchronous motor and a 3000-h. p., 3000-rev. per min., 50-cycle turbo-generator installed on the S. S. *Cuba*. The curves marked braking torque show the torque developed by the motor functioning as a generator with both 125 volts and 250 volts across the collector rings. The motor is connected to the generator with opposite phase rotation but the field of

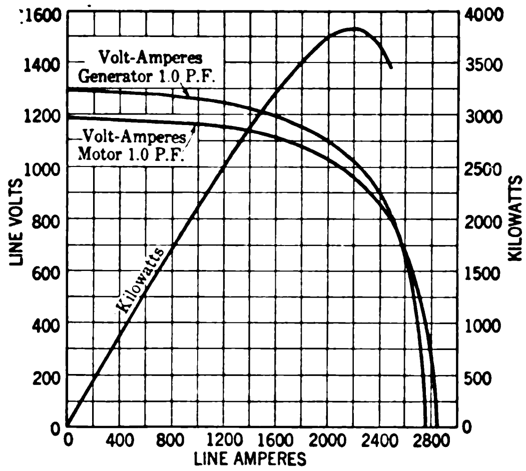

Fig. 8—Load Characteristic at Full Excitation—3000-H.P., 3000-Rev. per Min. Generator and 3000-H. P., 100-Rev. Min., Synchronous Motor

the generator is not excited. The curve marked induction motor torque is the torque developed by the amortisseur winding of the motor. For this curve the generator is running at one-fourth of normal speed and has twice the normal excitation voltage impressed across the collector rings. This double excitation is obtained by means of a 250-125-volt, three-wire exciter. During normal operation the generator and motor fields are connected across the 125-volt circuits and during reversal across the 250-volt circuit. The propeller torque curve given in Fig. 1 has also been plotted in Fig. 7. As mentioned before this curve is considerably higher than that of a single-screw vessel. Tests made on the S. S. *Cuba* showed that the propeller could be brought to rest from full speed in three and one-half seconds by means of braking with 220-volt excitation; in twenty-seven seconds by braking with 110-volt excitation; and in thirteen seconds with the motor operating as an induction motor.

The load characteristic of this equipment is given in Fig. 8. With 125-volt excitation across the collector rings, the margin in break-out capacity is 161 per cent for a steadily applied load. Somewhat

more than this can be safely carried when the load is a variable one such as will result due to the action of the waves and rough weather.

The successful application of synchronous motors to ship propulsion, therefore, marks another advance in the ever widening field of activity of this type of motor. It is certainly to be expected that the same high record of substantial and reliable performance that it has established in other lines of industry will be duplicated in the marine field.

The Electric Strength of Air under Continuous Potentials and as Influenced by Temperature

BY J. B. WHITEHEAD and F. W. LEE
of the Johns Hopkins University

The paper describes a series of experiments on the influence of temperature on corona-forming continuous potentials. The observations have been made on three sizes of wire of diameters 0.0251 cm., 0.0803 cm., and 0.0933 cm., and in each case at several values of temperature within the range 5 deg. cent and 70 deg. cent. At each temperature the pressure has been varied from a value in the neighborhood of that of the atmosphere downwards; reaching in the extreme cases the value 6.03 cm. of mercury. Within the range of values reached, as indicated above, the general form of the law of corona, as developed experimentally by a number of other observers, is found to be fulfilled. There are separate families of curves for positive and negative potentials as obtained by varying the pressure for each constant value of temperature.

The observations show that under constant conditions as to pressure and temperature a higher value of negative potential than positive potential is required to form corona.

As plotted graphically, the results seem to indicate that when larger wires are used corona appears at the same values of both positive and negative potential. The observations, however, have not been extended sufficiently to show this identity of value. This conclusion is at variance with the observations of a number of other experimenters, in particular those of W. S. Brown, who concludes that with larger values of diameter of wire negative corona may appear at lower values than positive corona.

The experiments substantiate the empirical laws developed by Whitehead and Peek, although the constants of the equations involved are higher than any heretofore observed. There is some indications that at temperatures in the neighborhood of 70 deg. cent. a departure from the empirical laws mentioned may set in.

Introduction and Historical Setting

THE LAW of corona formation on round wires in air has been devised empirically from the observations of a number of experimenters. It involves the electric intensity at the surface of the wire, the radius of the wire, and the relative density of the air.

The empirical law has been investigated over quite wide ranges of values of radius of wire and air density as dependent on pressure. Comparatively few attempts have been made however to study the influence of temperature on corona formation. This paper describes a series of experiments in which corona voltages have been measured at several temperatures within the range of 5 deg. cent. to 70 deg. cent., the pressure being varied in each case from that of atmosphere downward, in the extreme cases to 6.03 cm. of mercury.

Continuous potential has been used throughout the work. Various investigators have shown that with alternating corona voltages the maximum values of the wave are very closely, if not identically, the same as the continuous voltage values.

The law of corona had its origin in the laws governing the sparking between plates. Townsend[2], upon the experiments formed by J. B. Baille[1], first stated the relation for the sparking voltage in air as given by the formula

$$V = 39\,P\,S + 1700 \tag{1}$$

Where V = voltage between two parallel plates,
P = pressure of the gas,
S = the distance between the plates.

This formula by dividing through by $P\,S$ gave use to the relation

$$\frac{E}{P} = 39 + \frac{1700}{P\,S} \tag{2}$$

Since the electric intensity between the plates is uniform and therefore $\frac{V}{S} = E$. The relation concentrated the attention upon the electric intensity and not upon the total voltage. Townsend in his development of secondary ionization first showed that in a corona tube the distance S in the above formula is that of the path which an ion traverses in the greatest field and therefore is next to the wire. Under this consideration the above formula for the corona tube is,

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$$\frac{E}{P} = A + \frac{B}{r_w} \cdot \frac{1}{\sqrt{P}} \tag{3}$$

Where A and B are constants of the phenomena and r_w is the radius of the wire. This equation giving the law of corona formation was first developed experimentally by Whitehead, Peek and others, and Townsend has shown that it may be derived from his experiments on gaseous ionization at low pressures and that it is in accord with the theory of ionization by collision.

Whitehead[3] first determined these constants in a corona tube for air under normal conditions. Peek[11] later showed that the density or the pressure and the temperature together affected the formation of corona and established the density factor δ.

$$\delta = \frac{3.92\,P}{T} \tag{4}$$

where P = pressure of the gas in centimeters of mercury,
T = absolute temperature in degrees centigrade.

The corona formula then reduced to the form

$$\frac{E}{\delta} = A + \frac{B}{\sqrt{\delta\, r_w}} \tag{5}$$

which it has at present.

Whitehead[3] and Peek[11] carefully investigated the values of A and B with alternating potential by changing δ, r_w, humidity of the air and the material

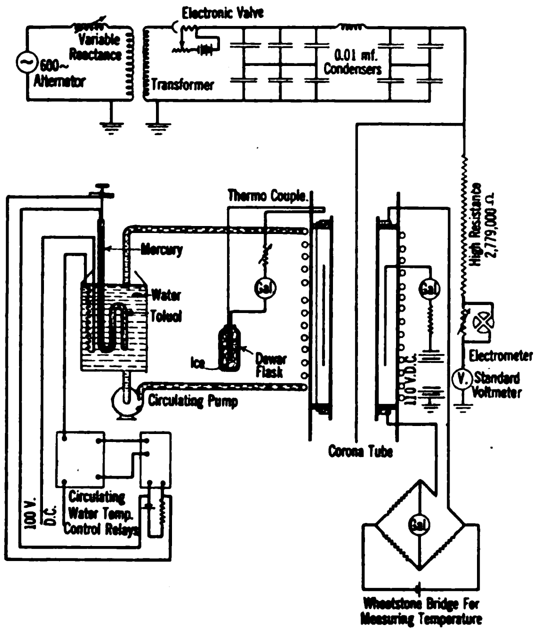

Fig. 1—Connection of High-Potential Voltage to Corona Tube and Auxiliary Apparatus

of the wire. Later Whitehead and Brown[3] also determined the constants A and B with continuous potentials by changing the diameter of the wire. Farwell[6], Watson[4] and Schaffers[5] also worked with direct potentials upon corona. Their method of detecting corona was mostly visual and with the methods and material available at that time they secured qualitative results which later experiments under more favorable conditions to a larger degree confirmed. It remained for Whitehead and Pullen[3] to develop a tube which gave more sensitive indications of corona.

This experimental investigation aims to continue the work of Whitehead and Brown[3] with continuous potentials. The immediate purpose was to investigate the constants A and B with positively and negatively charged wires under different temperatures and variable pressures at each temperature.

Description of Apparatus

The source of high continuous potential in these tests was secured from a "kenotron"* or rectifying vacuum tube, in connection with a high voltage transformer and condensers. Fig. 1 indicates the manner in which they were connected and how they were controlled.

The alternator was a two-armature generator designed to operate at either 600 cycles or at 3000 cycles and was directly connected to a three-h. p., 220-volt continuous-current shunt motor. The motor power, as well as the field excitation were secured from a 450-ampere-hour, 110-220-volt storage battery to insure steadiness of alternating potential.

The voltage to the transformer was controlled by a variable iron reactance. This reactance consisted of two coils mounted upon the legs of a core type transformer in which the core could be adjusted. The adjustment was accomplished by a screw having a pitch of twenty threads to the inch, and in this way the reluctance of the magnetic circuit was changed; and this in turn changed the ratio of voltage upon the transformer and the reactance coil. The generator voltage remained constant. In this way the high potential voltage could be raised in a continuous manner with an exceptional degree of adjustment.

In the high-tension circuit of the transformer a kenotron was connected in series with a battery of condensers, of which each unit had a capacity of 0.01 microfarad. The kenotron was designed for 40,000 volts and 1/10 ampere. In this experiment the voltage was limited by the condensers to 20,000 volts. The current taken by the exciting coil of the kenotron was six amperes for 100 per cent electronic emission. The resistance of the heating filament, a ten-mil tungsten wire was one ohm. The construction and theory of the kenotron are now quite well understood and thoroughly described by Dushman[7]. A small storage battery of six cells in series with a small carbon compression rheostat was sufficient to properly excite and regulate the filament current. The kenotron together with its exciting apparatus

*Name given by General Electric Company to a rectifing Fleming valve.

was carefully insulated from the ground by wooden insulators and logical grouping.

The condensers were of the oil-insulated high-potential type and were grouped into two batteries, one of six units, the other of four units each. The combined capacity of the first condenser battery was 0.015 microfarad and the combined capacity of the second condenser battery was 0.01 microfarad. The needle gap of each condenser was adjusted to 10,000 volts, thereby making the voltage across two condensers 20,000 volts. Between these two batteries was connected an inductance of 0.027 henry. According to Hull[8] the voltage fluctuation would be,

$$V = \frac{8\,i\,\pi}{L\,w^3}\left(C + \frac{1}{L\,w^2}\right)^2 \qquad (6)$$

$$= 4.62 \times i \times 10^{-10} \text{ volts}$$

where C = total capacity in farads,

$w = 2\,\pi\,f = 2\,\pi \times 600$ angular velocity in radians per sec.

L = coefficient of self-induction in henrys between condenser batteries,

i = current taken from the second condenser battery.

The current i which was used in the voltage measuring circuit never exceeded 0.01 ampere. From the above formula it is seen that the correction factor is negligible. That this coincided with experimental observations was tested by Brown[3].

The voltage was measured with a precision Weston voltmeter in series with a resistance of 1,428,000 ohms of manganin wire and of 1,343,000 ohms of lavite resistances. About 50 watts was the maximum rate of energy dissipation in the form of heat in this circuit. The quadrant electrometer connected as shown

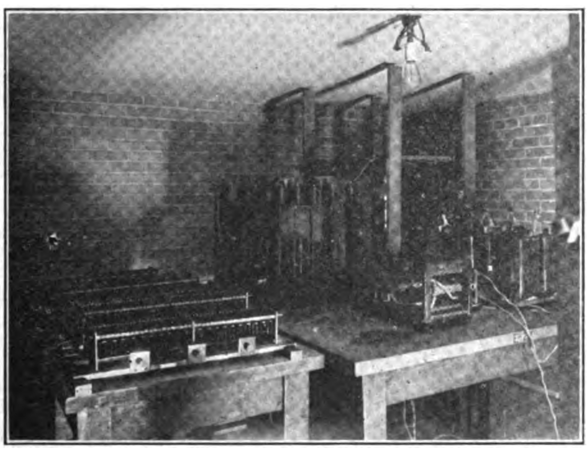

Fig. 2

was not used for detecting corona voltage, but for other purpose to be described later. The resistance in this circuit did not change within the range of 1 per cent in this experiment as tested by a Wheatstone bridge upon the summation of the individual units composing this resistance. (See Fig. 2.)

The corona tube as constructed for this experiment was similar to the one constructed before by Whitehead[3] and Pullen[3]. The main chamber was constructed from a piece of 6-in. steel piping 19 in. long. This pipe was carefully bored out in a lathe so as to receive the concentric cylinder supports and perforated corona cylinder. (See Fig. 3.) Around the inner 4-in.

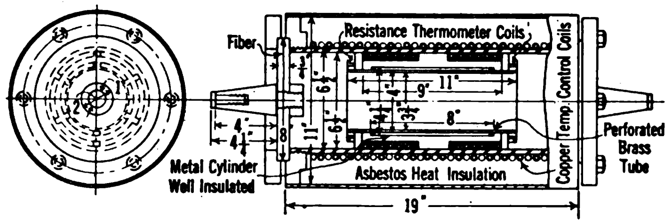

Fig. 3—Diagram Showing Construction and Dimensions of Tube

brass cylinder was another metal cylinder carefully insulated from it. This insulated cylinder received a small fraction of the corona current and, in conjunction with a galvanometer, served to indicate the presence of corona. (See Fig. 1.) The tube was closed at each end by a fiber head which also supported the central wire. Glass, one inch thick, was first tried for this purpose, but it was found that it was unable to withstand the stress due to internal pressure. The fiber used for this purpose was thoroughly boiled in paraffin to expel all moisture. Glass windows were inserted into this fiber to observe the condition of the wire at all times. Around the outside of this cylinder were wrapped coils of copper tubing to serve as heating or cooling coils to the apparatus. These coils of copper tube were further insulated as to heat on the outside by an asbestos heat insulating compound. Directly above and below the inside brass cylinder, but out of the electric field, were placed two copper wire coils each having a resistance of two ohms. These two coils were connected in series and served as a resistance thermometer. A thermocouple was also placed in the tube well away from the iron walls, to measure the temperature of the gas. The thermocouple was made with a very small heat capacity so as to quickly acquire the surrounding temperature, and thereby give an indication of any quick change of temperature of the gas inside of the tube. All of the joints were carefully packed with string first immersed in a packing compound. Insulated terminals were taken from the tube by the aid of spark plugs. The pipe joints were all well coated with litharge before finally adjusting them. All of the cylinders were machined to align centrally and the adjustment was within one-hundredth of an inch. Upon the outside of the tube was placed a spring, as shown in Fig. 4, which served to keep

the wire taut with changes of length of tube arising from the unequal expansion to the tube and its wire.

The temperature of the circulating water used in maintaining the temperature of the tube was controlled by a special thermostatic regulator. This regulator consisted of a glass tube of 3/16-in. bore, sealed at one end, filled with mercury and toluol, as indicated. Since the coefficient of volumetric temperature expansion of mercury is too small for

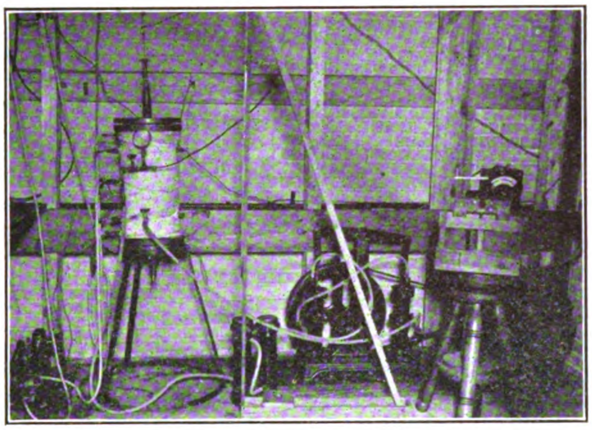

FIG. 4

sensitive regulation, toluol was also placed in this tube, as shown in the diagram of connections. The mercury acted as a seal for the very volatile toloul and at the same time served as a conductor in all the control circuits. The circulating water was heated with an immersion iron wire rheostat and was capable of carrying, when submerged, fifty amperes. This current was automatically interrupted by a remotely controlled switch, when the water had risen to its predetermined temperature. The control circuit of this switch was operated through a telegraph relay since it was necessary to interrupt this control circuit at a difference of potential of 110 volts d-c. A six-volt storage battery was used to excite this relay connected in series with a resistance. When the mercury in the tube had risen sufficiently high it short-circuited the battery connection to the relay and thereby opened the remotely controlled switch. As soon as the temperature receded this short circuit was removed and allowed the heating current to reestablish itself. The final temperature of the cirlating water was adjusted by means of a regulating screw. The height of this regulating screw determined the amount of expansion which the mercury and toluol could have before actuating the control circuits.

This constant temperature water was circulated by a positive rotary pump through the heating coils of the tube. By this method the corona tube reached a final steady temperature after one and one-half hours. The difference in temperature of the circulating water and of the gas in the tube was three degrees when operating in a steady state. Temperatures lower than room temperatures were secured by using cracked ice in the circulating water supply tank. The temperature of the circulating water in this case was that of melting ice, which was sufficiently constant for the experiment. In a like manner the temperature of one thermal junction was kept constant; only here a Dewar flask or thermos bottle was used to keep the ice from melting too rapidly.

The vacuum pump used to exhaust the corona tube was a small "Gyrek" model belted to a motor. (See Fig. 4.) The pressure was measured directly with a mercury manometer. Needle valves were used in all of the pressure control tubes to assure positive closing of the air connections.

From Fig. 5 it is seen that with the arrangement employed here it was possible to use but one lamp for illuminating the galvanometer mirrors, and also one scale sufficed to measure their deflection. The scale in this case was constructed from a ten-foot California redwood board bent into the arc of a circle of ten feet radius and mounted ten feet from the temperature measuring galvanometer. For indicating the presence of corona a D'Arsonval galvanometer slightly underdamped was used. This galvanometer ordinarily had a sensitivity of 83 megohms but with the above scale arrangement it was increased to 250 megohms.

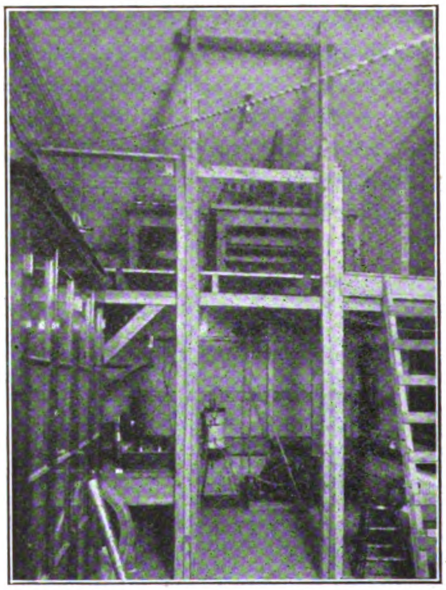

FIG. 5

It was found expedient, because of the large amount of apparatus used for operating this experiment, to separate the high-potential apparatus from the remainder by a platform. The platform was constructed above the corona tube, as is shown in Fig. 5. In this way it was possible to do all of the manipulating with dispatch and without any danger of coming into contact with high-potential circuits.

Preliminary Experiments

The method of securing high-potential direct-current voltage was substantially the same as that used by Brown[8]. However, it was found more convenient to control the alternating-current potential across the transformer with a reactance than with the field circuit of the alternator.

The voltmeter used in these tests was a precision Weston model No. 1064. It was, however, checked with a Weston standard cell and a Leeds and Northrup potentiometer through its entire range and was found accurate within the limits of observation.

The resistances of the voltage measuring circuit were measured with a Leeds and Northrup precision bridge and checked from time to time.

The thermocouple was made from a junction of "Advance" and copper wire and was calibrated with a standard mercury thermometer in a bath of water well agitated and slowly cooling. With the aid of a resistance in the copper portion of this circuit it was possible to adjust the deflection to an exact multiple of the temperature unit. One degree centigrade corresponded to a deflection of two divisions upon the scale. The resistance of the galvanometer was 110 ohms and the extra resistance in the circuit was 1161 ohms, thereby making a total of 1271 ohms in this circuit.

This thermocouple was then used to calibrate the resistance thermometer in the corona tube. According to Dellinger,[10] this resistance should have a linear variation of temperature within the range of temperature from 0 deg. cent. to 70 deg. cent. Its calibration will therefore check the accuracy of both the variation of mercury thermometer and of uniformity of

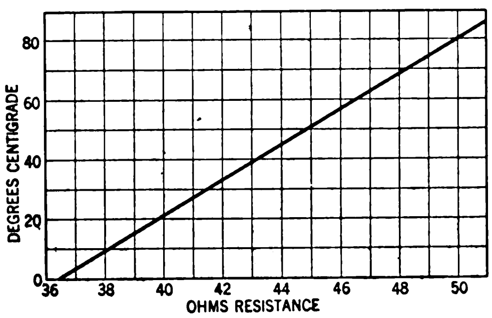

Fig. 6—Calibration of Resistance Thermometer With Thermocouple

temperature distribution in the tube. The temperature resistance curve upon this basis proved to be a straight line and hence the errors were below that of observation. (See Fig. 6.) The calibrating was done by first bringing the tube to a high steady temperature and then allowing it to cool slowly. It required six hours to secure this calibration curve.

The question of insulation was a more difficult one. It was found that the metal electrode cylinder around the perforated brass cylinder had a resistance to ground of 20 megohms through the hard rubber insulation. This was changed by replacing the insulators with new hard rubber.

Since the foundation of generating high direct potential by this method presupposes almost perfect insulation, it was necessary to check all of the leaks to ground in the generating system. This was done by charging the high-potential side of the system to a difference of potential of forty volts to ground and observing the decrease of potential upon the quadrant electrometer. The relations which exist by measuring the resistance by the loss of charge method are:

$$V = V_0 \epsilon^{-\frac{1}{CR}t} \tag{7}$$

where V = 34.7 potential at time t = 10 seconds.
V_0 = 39 initial potential,
C = 0.025 capacity in farads,
R = the resistance to ground.

This resistance from the observations as shown by the test was 38×10^9 ohms. It is safe to conclude that even under the highest voltages the leakage

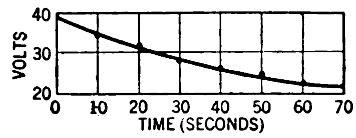

Fig. 7—Insulation Test With Quadrant Electrometer

current did not modify the potential within limits of observation. (See formula 6). Fig. 7 shows the insluation test with the quadrant electrometer.

Final Observations

The three wires chosen for this experiment had diameters 0.0521 cm., 0.0813 cm., and 0.0993 cm., respectively; the first two were german silver and the latter was steel. Each was carefully polished with crocus cloth and chamois skin before being placed in the tube. The wire was carefully placed in the tube and the tension applied for maintaining it straight. The diameter was measured before and after the test. The tube was now exhausted to 10 cm. of mercury absolute pressure and voltage was applied to the wire. If the corona which appeared around the wire was evenly distributed and gave no indications of beads, the wire was ready for observations. It was found advisable to begin at low pressures and gradually increase the pressure by letting air leak in through a needle valve. At low pressures the corona current from the insulated cylinder to the brass tube was very high as compared with the values at higher pressures.

The voltage which gave the first indication of a deflection in the corona indicating circuit was taken as the corona-forming voltage. The magnitude of this deflection, according to Whitehead and Pullen,[8] depended upon the number of ions per second which passed through the holes of the perforated brass

cylinder and gave up their charge to the insulated metal cylinder surrounding the brass one. It was expected and verified experimentally that the current in this indicating circuit was present only if the potential gradient was continued in the same direction as the gradient existing between the inside charged wire and the brass cylinder. A 110-volt storage battery was used to supply this potential gradient, as shown in the diagram of connections. In this battery circuit was connected a D'Arsonval galvanometer of 283-megohm sensitivity to indicate this portion of the corona current.

The polarity of the potential circuit was reversed by reversing the kenotron and the observations were repeated with reversed polarity. When this was done the polarity of the insulated metal cylinder was also reversed.

Each corona indication was repeated three times before a final reading was taken. The pressure, corona voltage, and temperature were observed simultaneously. Curves of voltage and pressure were plotted as the experiment progressed to check any false observation and to insure continuity. The temperature was then changed to another value and the observations repeated. All of the temperature and pressure observations were again repeated for the other wires. No difficulties were encountered with the wire charged positively; however, with the wire charged negatively care was necessary to register the voltage at the beginning of the corona cycle. The general form of the positive and negative corona indicating circuits are shown in Fig. 8.

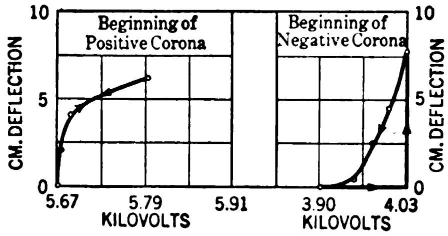

FIG. 8

The difference between these two characteristics was observed by Whitehead[3] and are under further investigation.

RESULTS OF OBSERVATIONS

For the analysis of the results of these experiments it was assumed that the electric intensity at the surface of a wire is given by the following relation:

$$E = \frac{V}{r_w \log_n \dfrac{D_t}{D_w}} \tag{8}$$

where V = the potential difference between the wire and the tube,

r_w = radius of wire in centimeters,

D_w = diameter of the wire,

D_t = diameter of the tube.

The value for these constants for all of the wires used is given in Table I.

TABLE I
WIRE DATA AND CORONA TUBE CONSTANTS

Diameter of Tube	3.75 in. inside measurement.		
" " Wire	No. 1	= 0.0205 in.	= 0.0521 cm.
" " "	No. 2	= 0.0320 in.	= 0.0813 cm.
" " "	No. 3	= 0.0391 in.	= 0.0993 cm.
Radius " "	No. 1	= 0.01025 in.	= 0.02605 cm.
" " "	No. 2	= 0.01600 in.	= 0.04065 cm.
" " "	No. 3	= 0.01955 in.	= 0.04965 cm.

$\text{Log}_n \dfrac{\text{dia. cylinder}}{\text{dia. wire}}$ No. 1 wire $\text{Log}_n \dfrac{3.75}{0.0205}$ = Log 183 = 5.2095 numeric

No. 2 " $\text{Log}_n \dfrac{3.75}{0.0320}$ = Log 1172 = 4.7638 "

No. 3 " $\text{Log}_n \dfrac{3.75}{0.0391}$ = Log 96 = 4.5643 "

(Radius of wire) $\text{Log}_n \dfrac{D_c}{D_w}$ No. 1 wire = 5.2095 × 0.02605 = 0.1358 cm.

or No. 2 " = 4.7638 × 0.04065 = 0.1936 cm.

$r_w \text{ Log}_n \dfrac{D_c}{D_w}$ No. 3 " = 4.5643 × 0.04965 = 0.2260 cm.

$\dfrac{1}{r_w \text{ Log}_n \dfrac{D_c}{D_w}}$ No. 1 wire $= \dfrac{1}{0.1358}$ = 7.375 1/cm.

No. 2 " $= \dfrac{1}{0.1936}$ = 5.170 1/cm.

No. 3 " $= \dfrac{1}{0.2260}$ = 4.430 1/cm.

Resistance of voltmeter No. Weston = 441.4 ohms 3-volt scale
No. scale divisions for 3 volts = 150 numeric.

Amperes per unit scale division $= \dfrac{3}{441.4} \times \dfrac{1}{150}$ = 0.00004536 amperes.

Resistance of voltage circuit 2,779,000 ohms.
Volts per unit scale division = 2,779,000 × 0.00004536 = 126 volts.

$$E = \frac{\text{Def.}}{r_w \text{ Log}_n \dfrac{D_c}{D_w}} = \frac{\text{Electric Intensity}}{\text{Unit Deflection}} \times \text{Deflection}$$

= No. 1 wire = 126 × 7.375 = 926 volts/cm. /unit deflection.
= No. 2 wire = 126 × 5.170 = 651 volts/cm./unit. deflection.
= No. 3 wire = 126 × 4.43 = 558 volts/cm./unit deflection.

The results were further analyzed in accordance with the relation (9), the work of all other investigators indicating that this relation is correct, and J. T. Townsend having shown that it is in accord with the theory of ionization by collision.

$$E = A\,\delta + B \sqrt{\frac{\delta}{d}} \tag{9}$$

where E = electric intensity,

A = a constant of the phenomena,

B = another constant of the phenomena,

δ = density factor $= \dfrac{3.92\,P}{T}$

P = the absolute pressure in cm. of mercury,

T = the absolute temperature in deg. cent.

TABLE II

POSITIVE CORONA

Applied voltage = 126 × deflection								Diameter of wire = 0.0205 in. = 0.0521 cm. E = 926 × deflection					
No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. H_g	Temperature Th. Cpl.	Res.	Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r cm.	$\frac{1}{\sqrt{\delta r}}$	$\frac{E}{\delta}$
1	19.9	2508.0	18380	7.28	19.5°	21°	293°	2525	0.0978	0.3718	0.0259	19.89	188000
2	24.5	3088.0	22600	10.38	"	"	"	2176	0.1392	0.3110	"	16.17	16230
3	27.9	3515.0	25750	13.13	"	"	"	1960	0.1765	0.2761	"	14.80	145800
4	31.6	3980.0	29170	15.98	"	"	"	1825	0.2145	0.2505	"	13.43	135800
5	36.8	4640.0	33950	20.48	"	"	"	1656	0.2755	0.2215	"	11.82	123200
6	41.3	5200.0	38100	24.23	"	"	"	1571	0.3262	0.2034	"	10.89	116800
7	46.0	5800.0	42400	28.48	"	"	"	1490	0.3830	0.1878	"	10.04	110600
8	50.2	6330.0	46300	32.28	"	"	"	1436	0.4340	0.1761	"	9.45	106800
9	54.2	6830.0	50000	35.93	"	"	"	1392	0.4830	0.1670	"	8.94	103400
10	57.8	7280.0	53300	39.28	"	"	"	1357	0.5275	0.1596	"	8.58	101000
11	62.7	7900.0	57800	44.08	"	"	"	1312	0.5920	0.1508	"	8.06	97800
12	67.1	8450.0	61900	48.70	"	"	"	1271	0.6540	0.1432	"	7.68	94800
13	72.7	9160.0	67100	54.48	"	"	"	1223	0.7310	0.1357	"	7.27	91800
14	78.4	9870.0	72300	60.43	"	"	"	1197	0.8100	0.1288	"	6.90	89300
15	85.2	10720	78600	67.83	19.5°	21°	293°	1160	0.9120	0.1216	0.0259	6.51	86200
1	22.2	2798.0	20470	10.11	70°	69°	342°	2050	0.1160	0.3145	0.0259	18.25	176800
2	25.0	3150.0	23050	12.76	"	"	"	1810	0.1462	0.2805	"	16.24	156700
3	33.1	4170.0	30520	19.71	"	"	"	1548	0.2260	0.2255	"	13.08	135100
4	37.4	4710.0	34500	23.76	"	"	"	1453	0.2720	0.2055	"	11.92	126800
5	41.5	5230.0	38300	27.86	"	"	"	1375	0.3198	0.1896	"	11.00	119900
6	45.3	5710.0	41700	31.96	"	"	"	1305	0.3662	0.1771	"	10.28	113900
7	48.9	6160.0	45100	35.91	"	"	"	1255	0.4120	0.1670	"	9.69	109300
8	53.7	6760.0	49500	40.91	"	"	"	1210	0.469	0.1563	"	9.08	105600
9	57.8	7280.0	53300	45.21	"	"	"	1182	0.519	0.1489	"	8.64	102700
10	62.8	7920.0	58000	51.46	"	"	"	1129	0.589	0.1395	"	8.11	98600
11	69.7	8790.0	64300	59.01	"	"	"	1090	0.677	0.1302	"	7.56	95100
12	76.2	9600.0	70300	66.61	"	"	"	1056	0.758	0.1228	"	7.15	92800
13	82.7	10410	76300	74.66	70°	69°	342°	1023	0.856	0.1159	0.0259	6.73	89200
1	20.1	2532.0	18530	8.24	52°	54°	325°	2253	0.993	0.3482	0.0259	19.72	186800
2	25.8	3250.0	23800	12.44	"	"	"	1913	0.150	0.2835	"	16.05	158700
3	29.8	3755.0	27500	15.74	"	"	"	1748	0.1899	0.2521	"	14.30	144800
4	32.3	4070.0	29800	17.99	"	"	"	1660	0.2168	0.2360	"	13.38	137300
5	36.6	4610.0	33750	21.89	"	"	"	1540	0.2640	0.2140	"	12.10	127900
6	40.8	5145.0	37650	25.84	"	"	"	1456	0.3120	0.1970	"	11.13	120600
7	44.8	5650.0	41300	29.74	"	"	"	1391	0.3585	0.1836	"	10.40	115200
8	48.9	6160.0	45100	33.89	"	"	"	1331	0.4080	0.1720	"	9.73	110200
9	52.6	6630.0	48500	37.64	"	"	"	1289	0.4540	0.1631	"	9.23	106900
10	57.3	7220.0	52800	42.59	"	"	"	1242	0.5140	0.1533	"	8.67	102800
11	62.2	7840.0	57400	47.89	"	"	"	1200	0.5760	0.1448	"	8.19	99600
12	66.0	8320.0	60900	52.24	"	"	"	1162	0.630	0.1382	"	7.93	96700
13	73.2	9225.0	67500	58.54	"	"	"	1152	0.706	0.1310	"	7.40	95700
14	77.4	9750.0	71400	64.74	"	"	"	1102	0.780	0.1245	"	7.04	91500
15	82.7	10410	76300	70.94	"	"	"	1078	0.855	0.1190	"	6.73	89300
16	87.8	11050	81000	76.49	52°	54°	325°	1060	0.921	0.1144	0.0259	6.47	88000
						NEGATIVE CORONA							
1	22.1	2885.0	20400	7.58	25°	27°	298°	2690	0.0997	0.3640	0.0259	19.70	205000
2	27.6	3479.0	25450	10.88	"	"	"	2342	0.1430	0.3035	"	16.42	178000
3	41.2	5190.0	38000	20.58	"	"	"	1849	0.2704	0.2210	"	11.96	140800
4	46.3	5840.0	42700	24.78	"	"	"	1724	0.3260	0.2010	"	10.89	131000
5	51.2	6450.0	47250	28.98	"	"	"	1632	0.3810	0.1862	"	10.08	123800
6	55.3	6970.0	51000	32.78	"	"	"	1557	0.4310	0.1749	"	9.47	118200
7	58.4	7350.0	53800	36.53	"	"	"	1475	0.4800	0.1656	"	8.97	112100
8	64.1	8080.0	59200	41.33	"	"	"	1432	0.5440	0.1559	"	8.42	108800
9	70.1	8840.0	64700	46.68	"	"	"	1386	0.6130	0.1466	"	7.93	105600
10	82.4	10380	76000	58.93	"	"	"	1290	0.768	0.1307	"	7.10	98900
11	90.0	11440	83800	66.73	"	"	"	1258	0.877	0.1228	"	6.64	95800
12	99.3	12500	91600	75.68	25°	27°	298°	1212	0.996	0.1151	0.0259	6.23	92100
1	18.5	2330.0	17080	6.30	68.5°	69°	342°	2710	0.0722	0.3990	0.0259	23.12	236200
2	24.3	3060.0	22400	10.05	"	"	"	2230	0.1151	0.3158	"	18.32	194500
3	28.3	3565.0	26100	12.75	"	"	"	2045	0.1461	0.2801	"	16.28	178900
4	32.2	4060.0	29700	15.80	"	"	"	1880	0.1812	0.2518	"	14.60	163900
5	37.1	4670.0	34210	19.85	"	"	"	1723	0.2275	0.2245	"	13.02	150600
6	42.3	5330.0	38100	23.95	"	"	"	1594	0.2745	0.2045	"	11.88	138900
7	46.4	5845.0	42750	27.80	"	"	"	1538	0.3190	0.1895	"	11.00	134100
8	51.1	6445.0	47100	32.10	"	"	"	1468	0.3680	0.1768	"	10.24	127900
9	54.7	6890.0	50450	35.65	"	"	"	1413	0.4090	0.1678	"	9.72	123200
10	59.0	7430.0	54400	40.25	"	"	"	1352	0.4615	0.1578	"	9.16	117800
11	63.4	7990.0	58450	45.65	"	"	"	1282	0.5240	0.1481	"	8.58	111300
12	67.2	8470.0	62000	51.35	"	"	"	1209	0.5880	0.1395	"	8.11	105300
13	71.0	8950.0	65500	57.70	"	"	"	1134	0.6620	0.1320	"	7.63	98900
14	76.3	9610.0	70400	66.95	"	"	"	1052	0.7670	0.1225	"	7.10	91800
15	82.4	10380	76000	74.70	68.5°	69°	342°	1019	0.8560	0.1160	0.0259	6.72	88800

TABLE II—*Continued*

NEGATIVE CORONA

Applied voltage = 126 × deflection

Diameter of wire = 0.0205 in. = 0.0521 cm. E = 926 × deflection

No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. Hg	Temperature Th. Cpl.	Temperature Res.	Temperature Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r cm.	$\frac{1}{\sqrt{\delta r}}$	$\frac{E}{\delta}$
1	22.5	2835.0	20750	8.39	52°	52°	325°	2480	0.1011	0.3456	0.0259	19.54	204500
2	27.3	3440.0	25200	11.69	"	"	"	2158	0.1410	0.2925	"	16.56	178900
3	32.4	4080.0	29900	14.84	"	"	"	2015	0.1790	0.2597	"	14.70	167000
4	38.6	4860.0	35600	19.89	"	"	"	1791	0.2400	0.2242	"	12.69	148200
5	44.2	5570.0	40750	24.59	"	"	"	1658	0.2963	0.2020	"	11.42	137600
6	45.9	5775.0	42300	26.4	"	"	"	1603	0.3182	0.1960	"	11.02	133000
7	48.9	6160.0	45100	28.29	"	"	"	1562	0.3410	0.1882	"	10.62	132200
8	50.0	6300.0	46100	29.69	"	"	"	1553	0.3580	0.1834	"	10.39	128800
9	52.8	6660.0	48700	32.29	"	"	"	1512	0.3903	0.1762	"	9.96	124600
10	54.3	6850.0	50100	33.69	"	"	"	1488	0.406	0.1722	"	9.76	123200
11	59.2	7470.0	54600	37.94	"	"	"	1440	0.457	0.1609	"	9.19	119400
12	64.8	8160.0	59750	43.39	"	"	"	1379	0.523	0.1520	"	8.59	114200
13	69.9	8800.0	64500	47.94	"	"	"	1346	0.578	0.1447	"	8.18	111700
14	75.2	9475.0	69400	53.89	"	"	"	1289	0.650	0.1365	"	7.71	106800
15	80.3	10110	74100	59.59	"	"	"	1243	0.719	0.1298	"	7.34	103000
16	84.3	10610	77700	65.99	"	"	"	1183	0.795	0.1232	"	6.97	97800
17	84.9	10690	78300	66.39	"	"	"	1180	0.800	0.1228	"	6.95	97900
18	88.9	11200	82000	70.34	"	"	"	1167	0.848	0.1192	"	6.76	96700
19	93.5	11780	86300	76.14	"	"	"	1134	0.918	0.1148	"	6.49	94000
20	94.8	11930	87500	76.49	52°	52°	325°	1145	0.921	0.1143	0.0259	6.47	95000

TABLE III

POSITIVE CORONA

Applied voltage = 126 × deflection

Diameter of wire = 0.0320 in. = 0.0813 cm. E = 651 × deflection

No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. Hg	Temperature Th. Cpl.	Temperature Res.	Temperature Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r_w cm.	$\frac{1}{\sqrt{\delta r_w}}$	$\frac{E}{\delta}$
1	30.9	3895	20100	11.14	6°	6°	279°	1805	0.1567	0.3000	0.04065	12.45	128500
2	36.1	4550	23420	14.14	"	"	"	1660	0.1988	0.2661	"	11.08	118100
3	40.9	5150	26570	17.00	"	"	"	1565	0.2390	0.2425	"	10.10	113000
4	47.7	6010	30980	21.29	"	"	"	1458	0.2992	0.2168	"	9.03	103900
5	53.7	6770	34900	25.29	"	"	"	1380	0.3558	0.1990	"	8.28	98300
6	64.7	8160	42000	32.84	"	"	"	1280	0.4610	0.1746	"	7.27	91400
7	70.3	8860	45750	36.74	"	"	"	1245	0.5160	0.1650	"	6.87	88700
8	76.7	9670	49900	41.29	"	"	"	1210	0.5800	0.1559	"	6.49	86200
9	84.7	10680	55000	47.64	"	"	"	1158	0.6700	0.1450	"	6.03	82300
10	93.2	11730	60700	53.54	"	"	"	1131	0.7520	0.1368	"	5.66	80600
11	101.8	12820	66200	60.04	"	"	"	1102	0.8450	0.1291	"	5.38	78400
12	113.0	14230	73600	68.24	"	"	"	1078	0.9590	0.1211	"	5.05	76800
13	123.6	15580	80500	76.04	6°	6°	279°	1058	1.0680	0.1149	0.04065	4.78	75300
1	24.3	3060	15800	7.92	20°	20.5°	293°	1997	0.1059	0.3555	0.04065	15.17	149500
2	30.6	3878	19890	11.47	"	"	"	1735	0.1532	0.2956	"	12.60	129600
3	36.9	4650	23950	15.35	"	"	"	1564	0.2052	0.2557	"	10.89	116700
4	42.9	5410	27900	19.10	"	"	"	1456	0.2555	0.2290	"	9.77	109100
5	48.8	6150	31800	23.12	"	"	"	1376	0.3092	0.2080	"	8.87	102100
6	54.9	6900	35750	27.44	"	"	"	1300	0.3672	0.1910	"	8.15	97200
7	61.0	7690	39750	31.87	"	"	"	1247	0.4260	0.1772	"	7.56	93100
8	67.3	8480	43800	36.52	"	"	"	1199	0.4880	0.1658	"	7.07	89600
9	75.2	9480	49000	41.37	"	"	"	1181	0.5530	0.1558	"	6.63	88400
10	82.3	10370	53600	47.67	"	"	"	1124	0.6380	0.1450	"	6.19	83800
11	88.8	11190	57700	53.02	"	"	"	1187	0.7100	0.1375	"	5.86	81300
12	105.2	13270	68600	65.97	"	"	"	1037	0.7810	0.1233	"	5.58	87800
13	112.8	14200	73500	72.07	20°	20.5°	293°	1018	0.9640	0.1179	0.04065	5.03	76300
1	27.6	3478	17930	10.53	50°	49.5°	353°	1670	0.1279	0.3082	0.0406	13.82	140500
2	32.6	4110	21180	13.53	"	"	"	1564	0.1642	0.2721	"	12.18	128800
3	37.8	4760	24570	17.08	"	"	"	1439	0.2070	0.2421	"	10.88	118700
4	43.7	5460	28390	21.28	"	"	"	1334	0.2581	0.2170	"	9.86	109800
5	57.3	7220	37230	31.43	"	"	"	1184	0.3815	0.1788	"	7.95	97700
6	63.3	7970	41100	36.03	"	"	"	1140	0.4370	0.1668	"	7.47	94100
7	69.3	8740	45020	41.03	"	"	"	1097	0.4980	0.1561	"	6.99	90600
8	76.1	9590	49490	46.03	"	"	"	1067	0.5620	0.1471	"	6.58	88000
9	84.1	10590	54670	53.08	"	"	"	1028	0.6450	0.1372	"	6.15	84700
10	91.8	11550	59690	59.48	"	"	"	1005	0.7210	0.1298	"	5.81	82800
11	97.5	12280	83400	64.33	50°	49.5°	353°	987	0.7800	0.1248	0.0406	5.59	81400

TABLE III—*Continued*

POSITIVE CORONA

Applied voltage = 126 × deflection								Diameter of wire = 0.0320 in. = 0.0813 cm. E = 651 × deflection					
No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. H_g	Temperature Th. Cpl.	Res.	Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r_w cm.	$\frac{1}{\sqrt{\delta r_w}}$	$\frac{E}{\delta}$
1	21.6	2710	14030	7.44	67.5°	67°	340°	1887	0.858	0.3670	0.0406	16.90	163700
2	26.9	3390	17480	10.54	"	"	"	1658	0.1217	0.3082	"	14.20	143900
3	36.2	4560	23510	16.89	"	"	"	1394	0.1945	0.2436	"	11.20	120900
4	41.1	5180	26730	20.34	"	"	"	1315	0.2345	0.2221	"	10.30	114000
5	46.2	5820	29990	24.34	"	"	"	1234	0.2805	0.2030	"	9.33	106700
6	51.6	6510	33510	28.44	"	"	"	1176	0.3281	0.1880	"	8.62	102300
7	56.4	7100	36630	32.04	"	"	"	1144	0.3695	0.1768	"	8.13	99200
8	61.4	7730	39890	36.29	"	"	"	1098	0.4180	0.1662	"	7.64	95500
9	68.4	8610	44420	42.19	"	"	"	1054	0.4750	0.1541	"	7.16	93700
10	74.0	9340	48030	47.14	"	"	"	1022	0.5430	0.1458	"	6.70	88400
11	80.3	10120	52150	52.49	"	"	"	995	0.6050	0.1381	"	6.35	86200
12	87.8	11060	57080	59.04	"	"	"	968	0.6810	0.1302	"	7.98	83900
13	93.9	11810	61000	64.29	"	"	"	950	0.7310	0.1248	"	5.77	83400
14	101.5	12790	66000	70.99	"	"	"	932	0.8180	0.1189	"	5.47	80700
15	107.0	13490	69640	76.29	67.5°	67°	340°	913	0.8800	0.1147	0.0406	5.26	79200

NEGATIVE CORONA

#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r_w cm.	$\frac{1}{\sqrt{\delta r_w}}$	$\frac{E}{\delta}$
1	24.3	3062	15800	6.07	6.5°	7.5°	280°	2600	0.0850	0.4060	0.0406	17.00	185800
2	33.3	4190	21620	10.48	"	"	"	2062	0.1466	0.3090	"	12.88	147500
3	39.7	5000	25800	13.57	"	"	"	1902	0.1898	0.2720	"	11.34	135900
4	48.3	6110	31370	18.47	"	"	"	1701	0.2582	0.2326	"	9.72	121600
5	56.3	7100	36560	23.27	"	"	"	1575	0.3260	0.2075	"	8.64	112300
6	63.2	7960	41000	27.47	"	"	"	1495	0.3845	0.1912	"	7.96	106600
7	68.5	8640	44500	31.07	"	"	"	1432	0.4350	0.1795	"	7.49	102400
8	74.6	9410	48400	35.10	"	"	"	1381	0.4910	0.1690	"	7.04	98800
9	81.9	10310	53200	39.87	"	"	"	1334	0.5580	0.1585	"	6.61	95300
10	89.1	11220	57900	45.02	"	"	"	1285	0.6300	0.1492	"	6.22	92000
11	98.7	12420	64100	51.27	"	"	"	1251	0.7180	0.1398	"	5.83	89300
12	117.2	14780	76200	65.07	"	"	"	1671	0.9100	0.1240	"	5.18	83800
13	129.9	16350	84400	74.22	6.5°	7.5°	280°	1137	1.0390	0.1160	0.0406	4.84	81300
1	27.3	3440	17830	8.38	20°	21°	293°	2115	0.1121	0.3455	0.0406	14.74	158000
2	36.8	4640	23900	13.33	"	"	"	1762	0.1783	0.2742	"	11.69	134100
3	42.2	5320	27440	16.28	"	"	"	1687	0.2175	0.2480	"	10.59	126400
4	48.2	6080	31340	20.23	"	"	"	1546	0.2705	0.2225	"	9.50	115700
5	60.9	7670	39590	28.38	"	"	"	1396	0.3795	0.1880	"	8.01	104400
6	66.5	8380	43200	32.33	"	"	"	1336	0.4320	0.1760	"	7.51	100100
7	72.4	9110	47000	36.38	"	"	"	1295	0.4860	0.1660	"	7.08	96900
8	78.2	9860	50900	40.70	"	"	"	1249	0.5440	0.1570	"	6.68	93800
9	84.6	10660	55000	45.33	"	"	"	1213	0.6060	0.1488	"	6.35	90800
10	93.3	11750	60600	52.08	"	"	"	1164	0.6960	0.1387	"	5.92	87000
11	104.0	13100	67600	59.98	"	"	"	1128	0.8030	0.1292	"	5.50	84200
12	110.7	13920	72000	65.33	"	"	"	1100	0.8740	0.1238	"	5.29	82400
13	118.9	14970	77200	71.43	"	"	"	1080	0.9550	0.1185	"	5.05	80800
14	125.5	15810	81600	76.43	20°	21°	293°	1067	1.0210	0.1144	0.0406	4.89	79800
1	24.1	3038	15670	7.18	50°	50°	323°	2180	0.0871	0.3740	0.0406	16.73	180000
2	28.9	3641	18790	9.53	"	"	"	1969	0.1158	0.3240	"	14.53	162700
3	34.2	4310	22240	12.33	"	"	"	1801	0.1497	0.2855	"	12.78	148700
4	48.8	6150	31750	21.53	"	"	"	1475	0.2615	0.2156	"	9.63	121600
5	54.8	6910	35620	25.53	"	"	"	1397	0.3100	0.1990	"	8.87	114900
6	61.0	7690	39650	29.83	"	"	"	1327	0.3620	0.1832	"	8.20	109400
7	66.7	8410	43300	34.13	"	"	"	1268	0.4140	0.1712	"	7.67	104700
8	72.5	9140	47130	38.18	"	"	"	1236	0.4630	0.1621	"	6.26	101700
9	78.7	9920	51200	43.18	"	"	"	1187	0.4240	0.1522	"	6.81	97800
10	85.7	10790	55700	48.53	"	"	"	1147	0.5890	0.1438	"	6.44	94500
11	95.1	11980	61800	55.68	"	"	"	1111	0.6750	0.1342	"	6.01	91700
12	103.6	13030	67400	62.38	"	"	"	1080	0.7560	0.1268	"	5.69	89300
13	114.6	14420	74600	71.93	"	"	"	1037	0.8720	0.1182	"	5.29	85500
14	121.0	15240	78800	76.43	50°	50°	323°	1031	0.9260	0.1142	0.0406	5.13	85000
1	24.6	3100	15990	7.74	68°	67°	341°	2069	0.0889	0.3600	0.0406	16.56	180000
2	31.8	4010	20660	11.54	"	"	"	1786	0.1328	0.2950	"	13.55	154600
3	39.3	4950	25540	16.08	"	"	"	1590	0.1848	0.2495	"	11.49	138400
4	65.1	8200	42310	33.93	"	"	"	1247	0.3900	0.1720	"	7.90	108400
5	70.2	7850	45600	37.88	"	"	"	1204	0.4350	0.1628	"	7.48	104800
6	75.3	9490	48940	42.38	"	"	"	1156	0.4860	0.1538	"	7.08	100600
7	81.6	10280	53060	47.43	"	"	"	1121	0.5450	0.1455	"	6.68	97400
8	88.5	11130	57530	53.53	"	"	"	1085	0.6160	0.1368	"	6.30	93400
9	100.3	12670	65320	63.79	"	"	"	1025	0.7310	0.1255	"	5.77	89400
10	108.1	13620	70350	70.69	"	"	"	996	0.8130	0.1192	"	5.47	86600
11	114.3	14410	74160	76.29	68°	67°	341°	973	0.8760	0.1146	0.0406	5.28	84700

TABLE IV

POSITIVE CORONA

Applied voltage = 125 × deflection

Diameter of wire = 0.0391 in. = 0.0993 cm. E = 558 × deflection

No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. H_g	Temperature Th. Cpl.	Temperature Res.	Temperature Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r cm.	$\frac{1}{\sqrt{\delta r}}$	$\frac{E}{\delta}$
1	22.4	2822	12490	5.75	5°	8.5°	280°	2171	0.0806	0.4170	0.04965	15.82	154900
2	27.5	3465	15350	8.10	"	"	"	1895	0.1138	0.3520	"	13.32	135100
3	34.4	4330	19180	11.45	"	"	"	1676	0.1602	0.2955	"	11.21	119500
4	42.8	5390	23910	15.75	"	"	"	1519	0.2205	0.2524	"	9.55	108200
5	47.6	6000	26580	18.45	"	"	"	1441	0.2582	0.2330	"	8.93	102800
6	56.2	7080	31350	23.35	"	"	"	1345	0.3270	0.2074	"	7.84	95900
7	64.8	8160	36140	28.25	"	"	"	1280	0.3960	0.1882	"	7.12	91400
8	74.0	9330	41170	34.20	"	"	"	1204	0.4790	0.1712	"	6.49	85900
9	83.1	10480	46300	39.80	"	"	"	1162	0.5575	0.1585	"	6.01	83200
10	91.6	11530	51200	45.40	"	"	"	1128	0.6360	0.1487	"	5.63	80500
11	100.0	12600	55800	51.10	"	"	"	1092	0.7160	0.1400	"	5.30	77900
12	111.6	14060	62300	58.50	"	"	"	1064	0.8200	0.1310	"	4.96	76100
13	120.6	15190	67400	64.85	5°	8.5°	280°	1038	0.9080	0.1242	0.04965	4.71	74200
1	28.3	3565	15800	8.73	21.5°	22.5°	295°	1812	0.1162	0.3385	0.04965	13.18	136000
2	35.0	4410	19530	11.98	"	"	"	1633	0.1591	0.2891	"	11.27	122800
3	41.0	5170	23910	15.28	"	"	"	1568	0.2028	0.2560	"	9.97	117900
4	47.4	5970	26450	18.98	"	"	"	1393	0.2520	0.2298	"	8.95	105000
5	54.0	6810	30170	22.78	"	"	"	1325	0.3022	0.2100	"	8.16	99800
6	59.8	7540	33490	26.48	"	"	"	1262	0.3520	0.1946	"	7.56	95200
7	69.0	8700	38550	32.38	"	"	"	1190	0.4300	0.1760	"	6.84	89500
8	75.3	9490	42080	36.58	"	"	"	1151	0.4860	0.1657	"	6.43	86600
9	82.3	10380	46030	40.78	"	"	"	1132	0.5420	0.1570	"	6.09	84900
10	89.2	11230	49760	45.68	"	"	"	1092	0.6070	0.1481	"	5.76	81900
11	97.3	12260	54300	50.81	"	"	"	1067	0.6750	0.1404	"	5.46	80500
12	102.9	12960	57430	54.68	"	"	"	1050	0.7270	0.1355	"	5.27	78900
13	111.4	14050	62200	60.38	"	"	"	1031	0.8020	0.1288	"	5.01	77600
14	125.8	15820	70200	70.66	21.5°	22.5°	295°	993	0.9400	0.1192	0.04965	4.63	75200
1	25.4	3200	14450	7.68	45.5°	46°	319°	1882	0.0944	0.3624	0.04965	14.60	153200
2	32.4	4080	18420	11.28	"	"	"	1633	0.1386	0.2980	"	12.05	133000
3	38.6	4860	21950	14.78	"	"	"	1484	0.1816	0.2614	"	10.56	120800
4	53.6	6760	30490	23.98	"	"	"	1272	0.2945	0.2045	"	8.27	103500
5	61.5	7750	34970	29.08	"	"	"	1202	0.3575	0.1858	"	7.50	97800
6	69.4	8750	39460	34.73	"	"	"	1136	0.4270	0.1700	"	6.86	92400
7	77.4	9750	44000	39.63	"	"	"	1110	0.4880	0.1591	"	6.42	90300
8	84.1	10600	47840	44.48	"	"	"	1074	0.5450	0.1500	"	6.07	87700
9	89.2	11220	50670	48.33	"	"	"	1037	0.5940	0.1440	"	5.81	85300
10	97.2	12230	55200	54.18	"	"	"	1019	0.6660	0.1360	"	5.50	82900
11	105.6	13300	59950	59.63	"	"	"	1006	0.7330	0.1297	"	5.24	81900
12	112.1	14120	63800	64.48	"	"	"	987	0.7920	0.1247	"	5.04	80600
13	120.0	15120	68200	70.43	45.5°	45°	319°	969	0.8650	0.1192	0.04965	4.83	78900
1	24.2	3050	13500	7.10	62°	63°	336°	1902	0.0828	0.3855	0.04965	15.60	163000
2	29.1	3670	16250	9.80	"	"	"	1660	0.1142	0.3195	"	13.29	142100
3	34.3	4320	19140	12.85	"	"	"	1489	0.1500	0.2790	"	11.60	127700
4	39.9	5030	22260	16.1	"	"	"	1381	0.1880	0.2495	"	10.37	118400
5	45.4	5720	25390	19.65	"	"	"	1291	0.2292	0.2257	"	9.38	110600
6	51.1	6440	28520	23.35	"	"	"	1222	0.2724	0.2070	"	8.60	104700
7	57.8	7280	32300	27.85	"	"	"	1158	0.3250	0.1895	"	7.87	99400
8	64.1	8080	35780	32.15	"	"	"	1112	0.3750	0.1765	"	7.33	95300
9	75.3	9490	42080	40.40	"	"	"	1041	0.4710	0.1575	"	6.54	89400
10	81.0	10200	45230	44.65	"	"	"	1014	0.5210	0.1498	"	6.20	86800
11	86.8	10930	48450	49.05	"	"	"	987	0.5730	0.1428	"	5.92	84500
12	93.2	11730	51980	54.35	"	"	"	956	0.6340	0.1357	"	5.64	82100
13	99.1	12490	55310	58.30	"	"	"	949	0.6810	0.1310	"	5.44	81300
14	104.6	13180	58350	62.25	62°	63°	336°	937	0.7260	0.1268	"	5.26	80300

NEGATIVE CORONA

1	30.0	3780	16740	7.63	4.5°	5°	278°	2195	0.1076	0.3622	0.04965	13.71	155000
2	39.2	4930	21870	11.48	"	"	"	1907	0.1620	0.2955	"	11.18	135000
3	47.2	5940	26350	15.43	"	"	"	1705	0.2178	0.2542	"	9.61	121000
4	54.8	6910	30630	19.48	"	"	"	1573	0.2745	0.2265	"	8.58	111400
5	63.6	8020	35520	24.24	"	"	"	1464	0.3420	0.2035	"	7.66	103900
6	72.2	9100	40280	29.28	"	"	"	1374	0.4130	0.1850	"	6.99	97700
7	79.3	10000	44200	33.38	"	"	"	1327	0.4700	0.1735	"	6.55	94100
8	85.6	10780	47760	37.28	"	"	"	1279	0.5260	0.1639	"	6.19	90600
9	94.2	11850	52590	42.03	"	"	"	1251	0.5930	0.1543	"	5.82	88800
10	101.4	12790	56630	46.78	"	"	"	1211	0.6600	0.1462	"	5.52	85800
11	108.3	13670	60470	50.88	"	"	"	1188	0.7180	0.1404	"	5.30	84100
12	115.0	14500	64200	55.58	"	"	"	1152	0.7830	0.1343	"	5.07	82000
13	124.9	15720	69600	61.88	4.5°	5°	278°	1126	0.8720	0.1273	0.04965	4.81	79900

TABLE IV—*Continued*

NEGATIVE CORONA

Applied voltage = 125 × deflection. Diameter of wire = 0.0391 in. = 0.0993 cm. E = 558 × deflection

No.	Defl.	Volts	Elec. Int.	Abs. Press. cm. H_g	Temperature Th. Cpl.	Temperature Res.	Temperature Abs.	Density Factor			Radius Wire		
#	D	V	E	P	t_c	t_r	T	$\frac{E}{P}$	δ	$\frac{1}{\sqrt{P}}$	r cm.	$\frac{1}{\sqrt{r\,\delta}}$	$\frac{E}{\delta}$
1	35.2	3430	19630	10.28	21°	21°	294°	1912	0.1370	0.3121	0.04965	12.12	143500
2	42.8	5400	23900	14.03	"	"	"	1703	0.1871	0.2670	"	10.49	127800
3	48.6	6130	27150	17.23	"	"	"	1574	0.2300	0.2410	"	9.35	117900
4	54.0	6810	30130	20.13	"	"	"	1498	0.2682	0.2230	"	8.66	112100
5	64.9	8180	36200	26.43	"	"	"	1370	0.3525	0.1948	"	7.55	102500
6	70.0	8820	39090	29.58	"	"	"	1322	0.3940	0.1875	"	7.14	99300
7	77.1	9730	43000	34.18	"	"	"	1261	0.4550	0.1714	"	6.65	94600
8	83.6	10520	46600	37.98	"	"	"	1228	0.5060	0.1625	"	6.31	92000
9	89.5	11280	49970	41.98	"	"	"	1189	0.5590	0.1547	"	6.00	89400
10	97.2	12240	54210	46.98	"	"	"	1152	0.6260	0.1461	"	5.67	86600
11	104.0	13110	58000	51.48	"	"	"	1127	0.6850	0.1395	"	5.42	84800
12	111.3	14040	62190	55.83	"	"	"	1112	0.7450	0.1341	"	5.20	83400
13	117.8	14820	65830	60.98	"	"	"	1078	0.8130	0.1282	"	4.97	81000
14	125.7	15820	70170	65.48	21°	21°	294°	1070	0.8720	0.1238	0.04965	4.80	80500
1	27.0	3401	15050	7.78	68°	68°	341°	1937	0.0894	0.3590	0.04965	15.04	168700
2	35.7	4500	19920	12.18	"	"	"	1637	0.1399	0.2874	"	12.02	142500
3	43.4	5470	24230	16.28	"	"	"	1488	0.1870	0.2480	"	10.40	129600
4	49.8	6280	27830	19.88	"	"	"	1401	0.2282	0.2243	"	9.42	122000
5	56.5	7120	31400	24.08	"	"	"	1304	0.2770	0.2040	"	8.54	113200
6	68.6	8650	38250	31.78	"	"	"	1203	0.3650	0.1778	"	7.44	104800
7	74.5	9520	41590	35.28	"	"	"	1179	0.4060	0.1687	"	7.05	102400
8	86.4	10880	48200	43.73	"	"	"	1099	0.5030	0.1514	"	6.34	95800
9	92.2	11610	51490	48.03	"	"	"	1071	0.5500	0.1443	"	6.06	93600
10	107.6	13550	60070	59.38	"	"	"	1012	0.6820	0.1299	"	5.44	88000
11	113.5	14300	63400	64.73	"	"	"	980	0.7440	0.1245	"	5.21	85200
12	128.6	16200	71790	75.78	68°	68°	341°	947	0.8700	0.1151	0.04965	4.82	82600

Expanding in the above formula

$$E = \frac{3.92\,A\,P}{T} + B\,\frac{\sqrt{\dfrac{3.92\,P}{T}}}{\sqrt{d}} \qquad (10)$$

Divide both sides of the equation by P

$$\frac{E}{P} = \frac{3.92}{T}\,A + B\,\frac{\sqrt{\dfrac{3.92}{T}}}{\sqrt{d}}\cdot\frac{1}{\sqrt{P}} \qquad (11)$$

If $\frac{E}{P}$ is plotted as ordinate and $\frac{1}{\sqrt{P}}$ as abscissa, then for a given absolute temperature T, the resultant curve, if A and B are constant, should be a straight line.

The slope of this line is $B\,\frac{\sqrt{\frac{3.92}{T}}}{\sqrt{d}}$.

The intercept is $\frac{3.92}{T}\,A$.

Also, if the formula is rewritten in the form

$$E = A\,\delta + B'\sqrt{\frac{\delta}{r}} \qquad (12)$$

where r = radius of the wire

$$B' = \frac{B}{\sqrt{2}}$$

Then

$$E = A + B'.\,\frac{1}{\sqrt{\delta\,r}} \qquad (13)$$

With this last formula it is possible to reduce all of the wires at all temperatures to the same law if

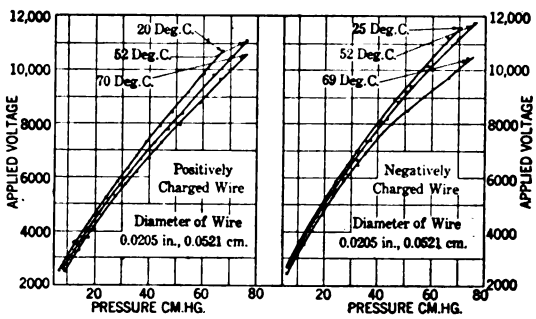

Fig. 9

A and B' are the same for all wires at all temperatures and pressures.

Accordingly, the various quantities have been computed and are given in Tables II, III and IV. Each table gives the electric intensity for corona at the wire, electric intensity divided by pressure $\left(\frac{E}{P}\right)$, electric intensity divided by the density factor $\frac{E}{\delta}$, the density factor δ and $\frac{1}{\sqrt{\delta\,r_w}}$, where r_w is the radius of wire in cm.

Curves showing the relation of applied voltage and

TABULATED RESULTS

Electric Int., $E = A\,\delta + B\,\dfrac{\sqrt{\delta}}{\sqrt{a}}$ kilovolts/cm.

Density Factor, $\delta = \dfrac{3.92 \times \text{pressure}}{\text{absolute temp.}}$

was made variable by changing the pressure and the temperature.

The above formula may be written

$$E/\delta = A + B' \cdot \frac{1}{\sqrt{r\,\delta}}$$

Where A = constant
B = constant
r = radius of wire (cm.)
a = diameter of wire (cm.)
B = constant
$B' = B/\sqrt{2}$

CORONA

Wire Chgd.	Temp. Deg. Cent.	Wire Diam.	Wire Radius	A	A aver. per wire	A aver. all wires	B	B aver. per wire	B aver. all wires	B' aver. per wire	B' aver. all wires
+	6°	0.0993	0.04965	41.6			10.2				
+	20°	"	"	39.1			10.2				
+	50°	"	"	39.2			11.21				
+	68°	"	"	38.3			11.00				
					39.5			10.56		7.46	
+	6°	0.0813	0.407	39.9			9.78				
+	20°	"	"	40.2			9.97				
+	50°	"	"	42.0			10.25				
+	68°	"	"	40.5			10.15				
					40.6			10.03		7.09	
+	21°	0.0521	0.0260	37.9			10.56				
+	52°	"	"	38.75			10.62				
+	70°	"	"	40.3			10.34				
					39.2			10.50		7.42	
						39.8			10.36		7.32
−	6°	0.0993	0.04965	37.9			12.4				
−	20°	"	"	37.5			12.28				
−	68°	"	"	44.8			11.60				
					40.1			12.09		8.52	
−	6°	0.0813	0.0407	40.3			11.79				
−	20°	"	"	40.4			11.23				
−	50°	"	"	41.7			11.57				
−	68°	"	"	41.8			11.71				
					41.0			11.57		8.17	
−	25°	0.0521	0.0260	30.7			12.12				
−	52°	"	"	39.0			12.24				
−	69°	"	"	41.0			11.85				
					40.3			12.07		8.52	8.41
						40.3			11.91		

With combined averages

$E = 39.8\,\delta + 10.36\,\sqrt{\delta/d}$ for + corona.
$E = 40.3\,\delta + 11.91\,\sqrt{\delta/d}$ for − corona.

or

$E/\delta = 39.8 + 7.32\,\dfrac{1}{\sqrt{\delta\,r}}$ for + corona.

$E/\delta = 40.3 + 8.17\,\dfrac{1}{\sqrt{\delta\,r}}$ for − corona.

BROWNS' RESULTS

$E = 33.7\,\delta + 11.5\,\sqrt{\delta/d}$ for + corona.
$E = 31.0\,\delta + 13.5\,\sqrt{\delta/d}$ for − corona.

FARWELL'S RESULTS

$E = 35.0\,\delta + 11.4\,\sqrt{\delta/d}$ for + corona.
$E = 31.6\,\delta + 11.9\,\sqrt{\delta/d}$ for − corona.

pressure were drawn for the positively and negatively charged wire, as shown in Figs. 9, 10, and 11. For the same pressure and temperature positive corona appeared at a lower voltage than the negative corona. Although the difference in temperature between two adjoining curves was only twenty degrees, less than 10 per cent upon the absolute scale, at no time is there doubt about the points of observation.

Curves showing the relation of $\dfrac{E}{P}$ and $\dfrac{1}{\sqrt{P}}$ are straight lines within errors of observation. (See Figs. 12, 13, and 14.) The positive and negative corona curves for each wire have a characteristic family. The positive curves show the smallest divergence for the same change in temperature. In the

tabulated results the values of A and B are stated for each wire at every constant temperature observation for a variation of pressure from 10 centimeters to

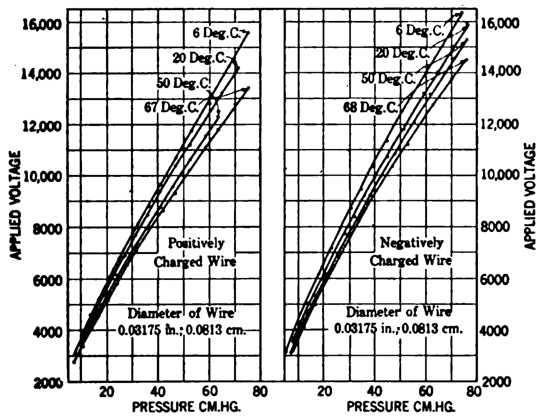

FIG. 10

70 centimeters of mercury. It is seen that B si always greater for negative corona.

The curves shown in Figs. 12, 13, and 14 were

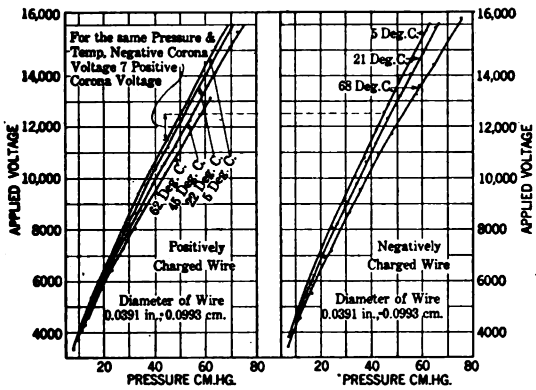

FIG. 11

reduced as explained by plotting $\frac{E}{\delta}$ and $\frac{1}{\sqrt{\delta r}}$ as ordinates and abscissas respectively. This allows

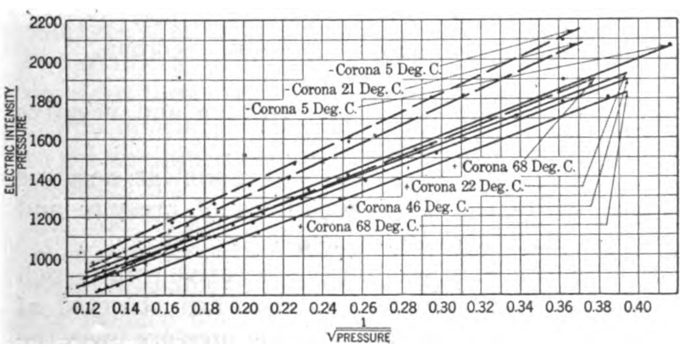

FIG. 12—POSITIVE AND NEGATIVE CORONA

Showing linear relation between

$\frac{\text{Electric intensity}}{\text{Pressure}}$ and $\frac{1}{\sqrt{\text{pressure}}}$

at different temperatures.

Diameter of wire = 0.0993 cm.

all of the points of the above observations to fall within a narrow zone whose width may be taken as an index of the accuracy of observations. (See Figs. 15, 16,

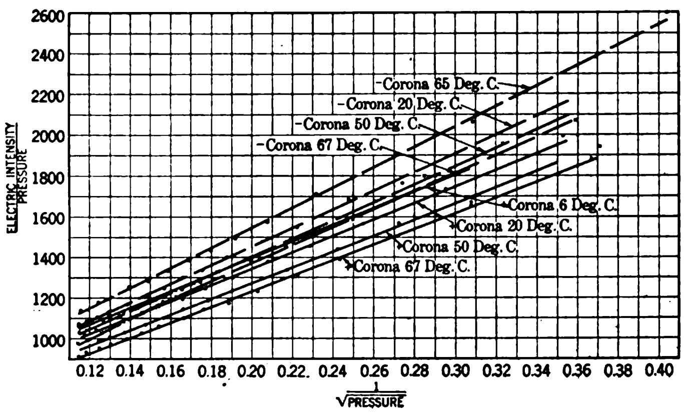

FIG. 13—(SAME AS FIG. 12, EXCEPT DIAMETER OF WIRE = 0.0813 CM.)

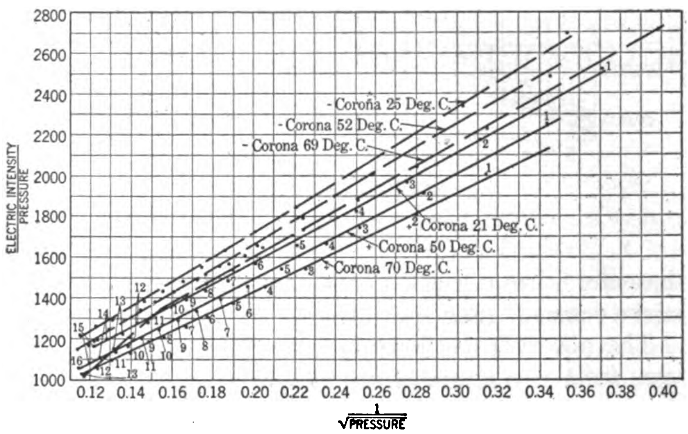

FIG. 14—(SAME AS FIG. 12, EXCEPT DIAMETER OF WIRE = 0.0521 CM.)

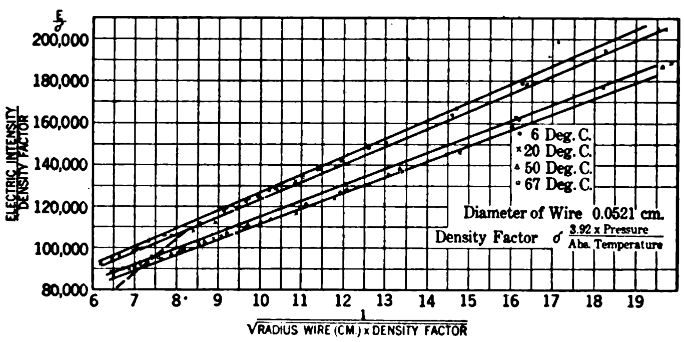

FIG. 15

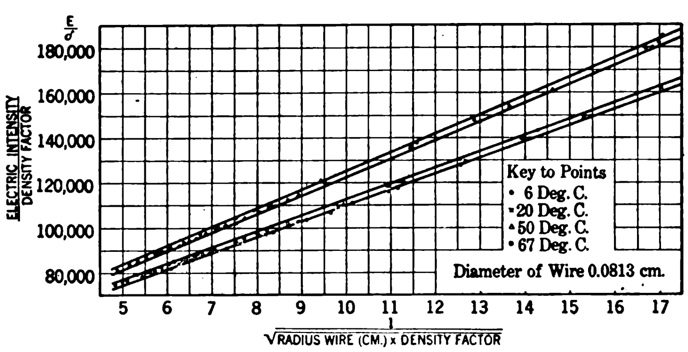

FIG. 16

and 17.) This zone is also a straight band which indicates that the original premises were well founded. In the tabulated results itsefra hwatohenesi iretc the average value for A is not very different but the average value for B has a distinct separate average for the positive and the negative corona respectively. The table also shows the value for B' in the later adopted form

$$\frac{E}{\delta} = A + B' \frac{1}{\sqrt{\delta\, r}} \qquad (13)$$

It should also be noticed that at the highest temperatnre of 69 deg. cent., especially with the smaller

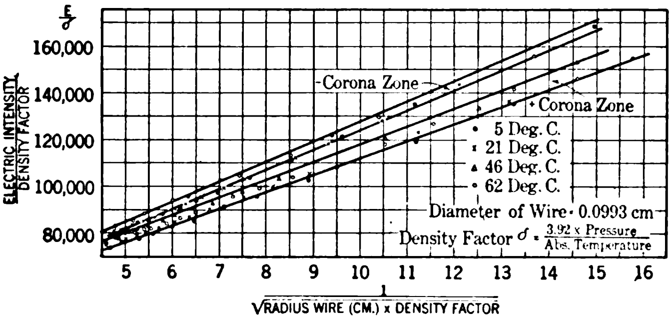

FIG. 17

diameter wire, a break in the continuity of the corona curve occurs. (See Fig. 14.)

The observations leading to these apparent departures from the fundamental law of formula (13) were repeated several times, and in each case yielded the results indicated. There is no obvious explanation why these breaks should appear in one set of curves and not in others in their neighborhood. Investigation of this interesting question is being continued.

DISCUSSION

The fact that positive corona starts at a lower value is in accord with the investigations of Farwell, Schaffers, Watson and Brown. It is in accord with the general theory of Townsend that negative ions are the active agents in the starting of corona. If the wire is positively charged they will move into an ever increasing field from a large region and hence will multiply more rapidly than if the reverse were true. According to Brown and Schaffers this principle fails when the value becomes less than a definite value. The results of this investigation indicate that the positive corona is always lower than the negative corona. Brown mentions great difficulty in securing definite negative corona readings. It was noticed in this investigation and discovered earlier by Whitehead[3] that negative corona occurs very abruptly from what seems a kind of supersaturated condition. If the negative corona is once formed the potential may be decreased below this corona-forming value with the corona phenomenon still persisting. The exact cycle of this phenomenon is at present under further investigation.

It is interesting to compare the value of the electric intensity as observed by Brown's relation upon the 0.0993-cm. wire. Brown states his positive corona formula

$$E = 33.7\,\delta + 11.5\sqrt{\frac{\delta}{d}} \text{ kilovolts per cm.}$$

Upon substituting the above value for d and using a density factor of unity

$E = 70.15$ kilovolts per cm.

If Farwell's relations are used

$$E = 35\,\delta + 11.4\sqrt{\frac{\delta}{d}}$$

$E = 71.15$ kilovolts per cm.

The results of this investigation give

$$E = 39.8\,\delta + 10.36\sqrt{\frac{\delta}{d}}$$

$= 72.6$ kilovolts per cm.

At pressures lower than atmosphere, both Brown's and Farwell's results indicate higher corona voltages than those found in these experiments. It should be stated that this is the only observation in which the field of these experiments touches that of Brown and Farwell.

CONCLUSIONS

1. The critical corona-forming electric intensities of these wires, ranging in size from 0.0521 to 0.0993 cm., at several constant temperatures in the range 5 deg. to 70 deg. cent. and at various pressures for each temperature have been investigated under continuous positive and negative potentials.

2. The critical surface intensity at which corona started upon the above wires can be summarized in the relation

$$E = 39.8\,\delta + 10.36\sqrt{\frac{\delta}{d}} \text{ for + corona}$$

$$E = 40.3 \quad + 11.96\sqrt{\frac{\delta}{d}} \text{ for − corona.}$$

3. The constant A in the positive and negative corona relation is the same.

4. Within the range of this experiment negative corona, under the same conditions of pressure and temperature, always occurs at a higher value.

5. The curves of positive and negative corona each form a separate family of curves when observed at the same temperature with variable pressure upon the same wire.

6. The observations give accordant results with Farwell and Brown when used under pressure and temperature conditions of observation at which their data were taken.

7. The results of the investigation are in accord with Townsend's theory of secondary ionization.

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Some Phases of Railroad Telegraph and Telephone Engineering

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(*Concluded from page* 325 *of JOURNAL for April*, 1921)

SELF-BALANCING DUPLEX

Based upon the idea of a duplex being a three-wire circuit, successful use has been made of a real line instead of the usual artificial line resistance box and condensers which are standard equipment in duplex sets. This "real" balancing line balances the regular line almost perfectly under changing weather conditions, needs no additional balancing at such times and hence can be designated "self-balancing." It also balances for inductive disturbances to which both line and balancing line are exposed and for line irregularities such as short lengths of cable. This assumes that the duplex line and its balancing lines are alike in characteristics; are on the same pole line; have the same length; kind of wire, and, in fact, are twins. The two sides of a composite are very good for this type of set-up, but the plan is also applicable to any two similar circuits, such as straight wires or simplexes provided they are reasonably alike in kind.

One difficulty experienced in lining up a duplex is to get an adjustment of resistance and capacity in the artificial line which will so nearly balance the actual line that no kick will be felt in the home polar relay when the home pole changer is operating. It is almost impossible to get such a balance, and furthermore, the balance must be changed for changing weather conditions. It is, therefore, unsatisfactory to work a duplex circuit having a repeater station on it that does not have an attendant the full period of the day in which the circuit is expected to give service.

This plan of self-balancing duplex is especially valuable for circuits that are unattended at repeater stations for a part of the day and on Sunday. It has been the custom in some instances to cut the repeater out during the hours the station is unattended, but this makes a long and unsatisfactory circuit.

The plan may be considered an extravagant use of wire, because it uses two wires for one duplex, but it is only suggested as an expedient for use where some circuits are idle after business hours, as many duplexes are at night and on Sunday, at which time they can be put to productive use for balancing a wire that must give twenty-four hour service.

Some oscillograms have been taken that illustrate the effect of lack of good capacity balance in the artificial line, and the perfection of the balance with a real line instead of an artificial line. It should be kept in mind that in the latter the balance is continuous and unchanging, whereas the artificial line needs attention intermittently.

In oscillogram No. 469 of Fig. 18 the outgoing line wave of a bridging quadruplex set on a 140-mile, No. 8 B. W. G. iron wire, high-resistance simplex, is trace No. 1 while the home key is operating. Trace No. 2 is the artificial line under the best balance that the attendant was able to get with the milliammeter as a guide. Trace No. 3 is the wave in the polar relay and shows plainly that the home pole-changer affects it considerably, evidenced by the kicks in trace No. 3 which occurred on the reversal of the line wave.

Oscillogram No. 470 is the same set on the same circuit with no difference except that all the capacity was removed, which greatly amplified the kick in the polar relay, trace No. 3, as would be expected. Oscillogram No. 540 is the same circuit with duplex sets. Oscillogram No. 588 shows the results with the self-balancing duplex on a 140-mile, No. 9 A. W. G. copper wire low-resistance type phantom, composited, in which it is readily apparent that the kick in the polar relay is very slight and a great improvement over the best balance that could be obtained on the artificial line. The slight waves in the polar relay wave be-

tween reversals of line current are probably reflected waves.

In Fig. 26, which indicates self-balancing duplexes applied at an unattended repeater station, the artificial line is cut off at switches No. 11 and No. 12, where the real lines to be used as balancing lines are cut in, which requires a special connection in existing duplex sets. Terminal stations are shown with duplex sets connected to these balancing wires, with no change except to cut off the battery at the seven-point switch and put on ground contact, which is regularly provided for in the seven-point switch. If lines No. 2 and No. 4 are regularly duplexed, their duplex sets are simply grounded at the seven-point switch. The resistance and capacity in artificial lines No. 8 and No. 10 can roughly approximate the values required in the artificial lines No. 7 and No. 9. This does not need to be exact, although it is about as easy to make it so as to have it inexact.

This set-up can be quickly arranged and, it is believed, is worth the trouble where circuits are idle, although the station may be attended, because it gives better service and needs no attention. It is quite often the case that the night and Sunday repeater attendants are the less experienced men of the force, and service will be better if they do not have to attempt adjustments of the duplex apparatus or repeaters. The plan is equally applicable and advantageous for differential and bridging duplexes.

No. 5-U Retardation Coil in Bridging Duplex and Quadruplex is Also Auto-Transformer

The action of the No. 5-U coil of bridging duplexes and quadruplexes was an object of curiosity, the work performed by the coil being difficult to determine with certainty, and a large number of oscillograms was taken to reach conclusions. From these it can safely be asserted that the No. 5-U coil functions primarily as an auto-transformer and incidentally as a retardation coil.

The traditional explanation ever since Brown designed this circuit arrangement is that an incoming wave from the line meets great opposition in its attempt to flow through the line side of the No. 5-U coil, because of the high impedance of the latter, and as a result almost all of the incoming current rushes into the polar relay which is connected across from line to artificial line. The explanation stopped at this point and neglected to state where this rush of current through the polar relay proceeds to. It does not go through the artificial line to ground, because the current is coming toward the No. 5-U coil at this time, and while this current is influenced slightly in value by the incoming line current it is not reversed nor is it greatly reduced. If the impedance of the line side of the No. 5-U coil were effective in stopping the inrushing line current, the artificial line side of it should be equally effective in stopping the rush that passes through the polar relay. No explanation has been made for the condition of outgoing current which also occurs due to the operation of the distant pole-changer.

In the quadruplex, the condition existing with the home keys and distant common key closed and distant polar key working will be discussed first. Oscillogram No. 471 of Fig. 28 shows the current in the line as trace No. 1, in the artificial line as No. 2 and in the polar relay as No. 3, of a bridging quadruplex on an Indianapolis-Bellefontaine, 140-mile, No. 8 B. W. G. iron wire telephone pair, simplexed with the ordinary high-resistance simplex used with direct-current selectors as shown in Fig. 10 but without the composite equipment, and balancing at 4400 ohms with one microfarad and 500 ohms in the first condenser, and 400 ohms and 3/4 microfarad in the second condenser. The distant polar key is sending the impulses and the other keys are closed. It is apparent from No. 471 that the artificial line current is only

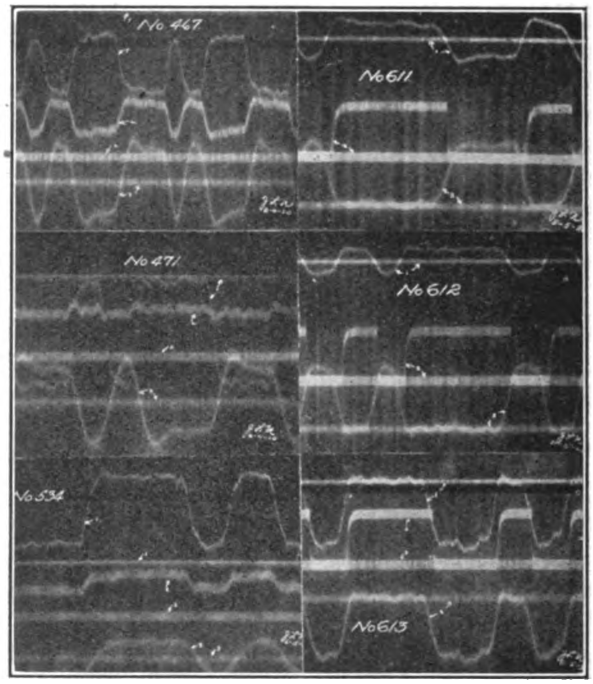

Fig. 28

slightly changed by the change of line current with operation of the distant polar key. Oscillogram No. 467 was taken under the same line conditions as No. 471 but shows the current in the line side of the No. 5-U coil as trace No. 1, the artificial line side as No. 2 and in the polar relay as No. 3. The difference in the values of current in the artificial line as shown in No. 471 and the artificial line side of the No. 5-U coil in No. 467 is very marked, and the difference represents the polar relay current.

With all keys closed the current is "upward" in the polar relay, *i. e.*, the direction indicated by an arrow on Fig. 29 pointing to the top of the page. It is also flowing toward the home pole-changer through the No. 5-U coil windings. Fig. 29 gives the current values and direction of flow on a bridging quadruplex during the steady state, for the different positions of

the keys, as actually measured on a working circuit. Fig. 30 gives actual current values in a differential quadruplex on the same circuit, for comparison.

Now, if the distant polar key opens, positive potential is applied there and current begins to flow in from the distant station. The potential wave will cause current to flow through the line side of the No. 5-U coil and will quickly increase the potential across this coil, during which time the current will decrease through the polar relay, and when the potential across the line side of the No. 5-U coil equals the potential across the artificial line side, the polar relay current at that instant will be zero but rapidly changing in direction. The transient state continues, that is, there is no hesitation at the zero point and the current reverses in direction through the polar relay.

When the distant polar key closes again, negative potential

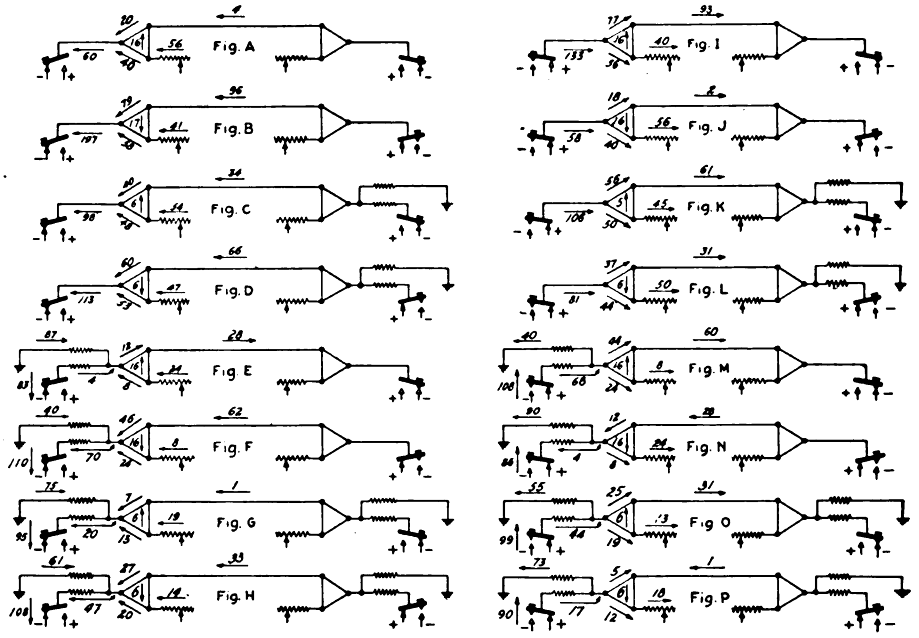

FIG. 29—APPROXIMATE CURRENT VALUES IN BRIDGING QUADRUPLEX FOR VARIOUS KEY POSITIONS

240 volts each end

Balance artificial line	2650	ohms
Home lamp resistance	−524	"
" " "	+524	"
Distant lamp "	−501	"
" " "	+486	"

Wires 57-58 No. 9 A.W.G. message simplex copper.
A-C. selector, low-resistance simplex.
Indianapolis-Bellefontaine

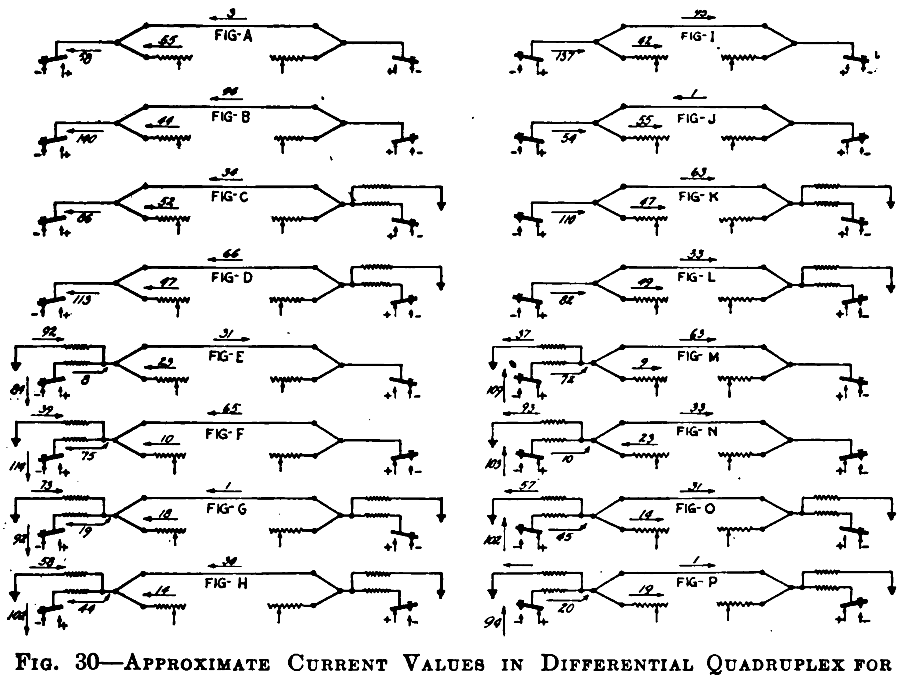

FIG. 30—APPROXIMATE CURRENT VALUES IN DIFFERENTIAL QUADRUPLEX FOR VARIOUS KEY POSITIONS

240 volts each end

Balance artificial line	2900	ohms
Home lamp resistance	−524	"
" " "	+497	"
Distant lamp "	−473	"
" " "	+483	"

Wires 57-58 No. 9 A. W. G. message simplex copper.
A-C. selector, low-resistance simplex.
Indianapolis-Bellefontaine

is applied there and the line current decreases and becomes nearly zero. The traditional explanation does not mention this action which leaves the impression that the movement of the polar relay armature both to and from the marking contact is due to "incoming" waves of current. In fact, the movement away from the marking contact is due to increase or rise of incoming current in the line, and the movement toward the contact is due to decrease or fall of line current, provided the home polar key is closed. If the home key is open, then the movement of the polar relay armature is due to just the reverse set of current actions, *i. e.*, the movement away from the marking contact will occur with decrease of outgoing line current and will move toward it with increase of outgoing line current. The current in the line will be flowing from the home station when the home key is open.

It will be remembered that the No. 5-U coil windings are both

wound on the same core and have a common terminal. The incoming and increasing current in the line side when the distant polar key opens, tends to build up a magnetic field in this core. This induces current in the artificial line winding by mutual induction or transformer action and in the same directional relation as in the line side; *i. e.*, if the line current is increasingly flowing toward the common terminal of the two windings, the generated current in the artificial line side will be toward this point, as follows from the laws of mutual induction. The magnetic flux of this generated current is nearly equal and opposite to that in the line side, and hence, the net change in flux is slight. As the current rapidly increases in the line side of the coil, it also rapidly increases in the artificial line side, thus creating a large difference of potential between the two line terminals; it is to be remembered that the common terminal can have only a potential common to both. This change of potential across the line terminals, which is across the polar relay, causes the reversal of current through the polar relay and throws the armature to the spacing position.

The oscillograms fail to show any great "rush" considered as rate of change of current value, but do show that the current continues to increase in value after reversal has occurred, to perhaps 20 per cent higher value than it does if the No. 5-U coil is replaced by 500-ohm resistances. If the No. 5-U coil is removed and two 500-ohm non-inductive resistances are put in its place, the current through the polar relay loses its tendency to rise beyond the value it has after reaching the steady state. Oscillograms No. 611 and No. 612 illustrate this, with No. 1 as polar relay trace, No. 2 as the polar relay local sounder circuit trace and No. 3 as the line trace. The No. 611 has the No. 5-U coils and shows that the polar relay current at each reversal continues beyond its ultimate value considerably and then gradually recedes. The No. 612 has 500-ohm resistances and the current in the polar relay reverses and reaches the steady value without the tendency to "bulge" beyond that value.

These two oscillograms were taken on one side of the low-resistance composited phantom, Indianapolis to Bellefontaine, No. 9 A. W. G. copper a-c. selector telephone dispatching line with the bridging duplexes balancing at 1800 ohms, three microfarads and 100 ohms in the first condenser, and two microfarads and 600 ohms in the second condenser, with 160-volt main battery at each end. The polar relay has an ordinary or usual adjustment, and both No. 611 and No. 612 show that the polar relay armature is reversed before the current change has ceased in the polar relay, and it is evident that the bulge of current in the set with the No. 5-U coil serves no useful purpose other than to hold the polar relay armature more solidly against its contact after it gets over. From the evidence gathered in these investigations it is not apparent that the current changes at any greater rate in the set with the No. 5-U coil than in the one with the 500-ohm non-inductive resistance. A similar record of a differential duplex and its polar relay local sounder circuit is given in No. 613 for comparative purposes. It was taken on the same circuit as were No. 611 and No. 612. In No. 613, traces No. 1 and No. 3 are both the line current.

For the bridging quadruplex the result of comparison of the No. 5-U coil and the 500-ohm resistances is shown by No. 469 of Fig. 18 for the No. 5-U coil and No. 534 of Fig. 28 for the 500-ohm resistances, both taken on the 140-mile, No. 8 B.W.G. high-resistance iron simplex circuit. In these, trace No. 1 is the line side of the No. 5-U coil, No. 2 is the artificial line side of the No. 5-U coil and No. 3 is the polar relay current. The common or neutral keys are closed.

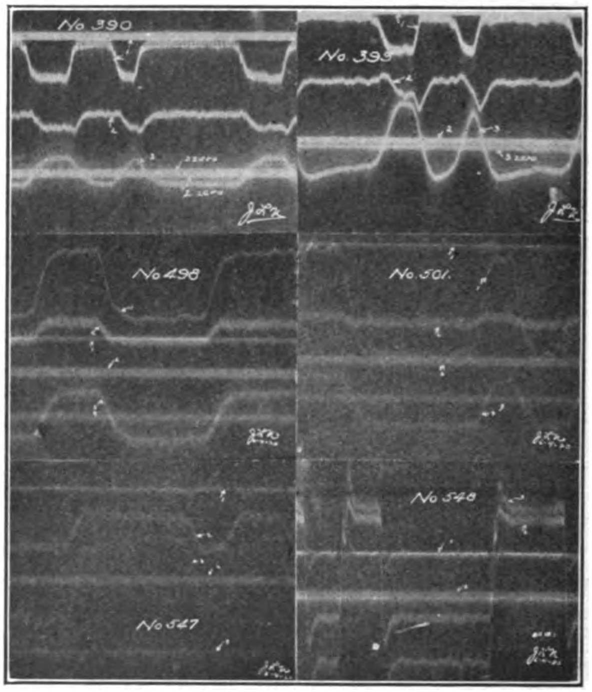

Fig. 31

This tendency to bulge or exceed the ultimate steady state value is more striking in the Goslin quadruplex, as illustrated in No. 390 of Fig. 31 for the non-inductive winding, and No. 393 with the No. 5-U coil. In this arrangement the polar relay and neutral relay are in series across the terminals of the No. 5-U coil and get less current in the bridge after the steady state is reached than does the regular quad, and due to the No. 5-U coil tending to equalize the current through its two windings during the transient state, the polar relay current is considerable.

It will be noted in No. 467 of Fig. 28 that after the first rush ends, the line side current in the No. 5-U coil continues to increase slowly and the artificial line slowly decreases, both changing by about the same

amount, until the steady state is reached. This time to reach the steady state in these bridging sets is longer than the average dash, as seen in the letter "a" which is being repeated in these oscillograms.

Two quadruplex sets were made up of non-inductive resistances throughout, simply maintaining the skeleton outlines of the bridging quadruplex; that is, there were no coils or relays used, simply resistances of the same values as the pieces of apparatus they replaced. These were placed on the same No. 8 B. W. G. iron wire simplex circuit as that on which No. 467 and No. 471 of Fig. 28 were taken. No. 498 of Fig. 31 corresponds to No. 467 as to location of recording elements of the oscillograph, and No. 501 similarly corresponds to No. 471. In No. 498 and No. 501 it is evident that the rate of reversal of current through the polar relay branch of the circuit is the same as with the regular polar relay and No. 5-U

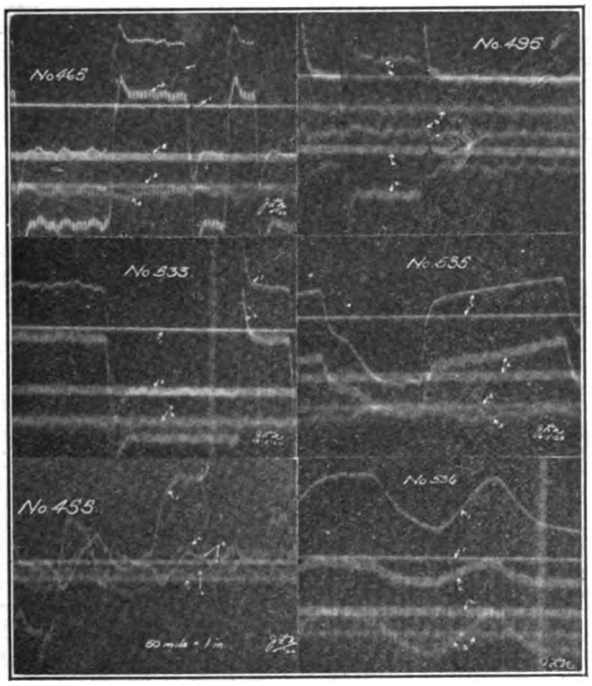

Fig. 32

coil, but the change ceases sooner with the non-inductive circuit, although the line waves are very closely the same in both arrangements.

Comparison shows clearly how the steady state is quickly reached in the polar relay in the non-inductive resistance circuit used in place of the No. 5-U coil illustrated in No. 498; whereas, there is considerable slant or gradual change in the inductive No. 5-U coil illustrated in No. 467.

A search coil of 250 ohms was wound on a No. 5-U coil of a duplex set and connected to the oscillograph, giving the result shown in No. 547 of Fig. 31 as No. 1 trace, with the distant station sending on the polar key. This shows that the change in magnetism in the core of the No. 5-U coil is very slight, consisting of small humps in the trace No. 1 at each reversal of the line current, while the current in the two sides fluctuates widely, which indicates that the coil is a very efficient transformer and as in power transmission, comparatively large power is transformed with a relatively small magnetizing current.

In the case of the current waves set up by the action of the home polar key when sending as shown in No. 548 of Fig. 31, the magnetism is considerable, as shown by the large sharp peaks of trace No. 1 made by the search

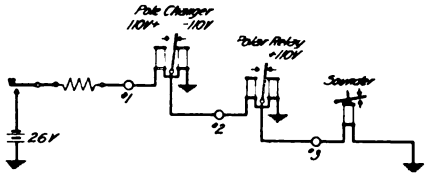

Fig. 33—Polar Relay Test Circuit

coil. This is somewhat due to the lack of proper and exact "balance," *i. e.*, the capacity, resistance and inductance of the artificial line is not exactly the same as the real line and the terminal apparatus at the distant end of the line.

These peaks of magnetism in the core of the No. 5-U coil cause the rounding off of the line wave of the

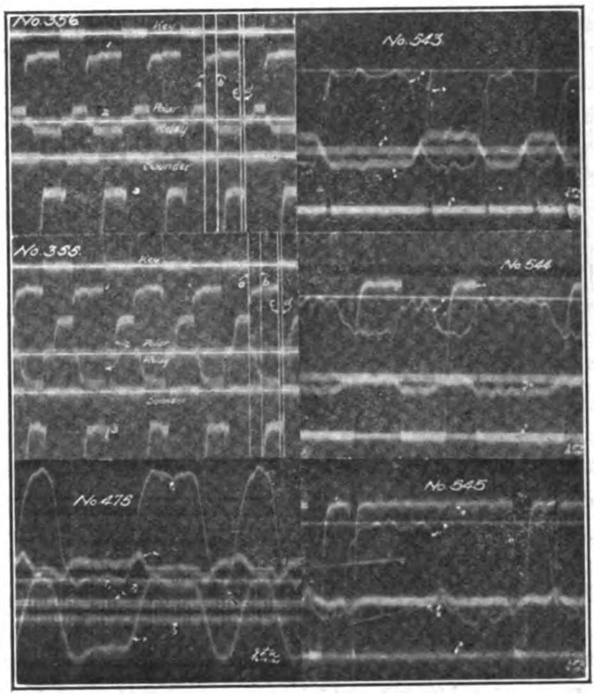

Fig. 34

home key operation, which is one of the chief features aimed at in the bridging sets. If no magnetic flux resulted due to the outgoing wave, the coil could be considered as non-inductive to outgoing waves and would show no great difference in the outgoing wave from that of the differential sets which have very sharp peaked out going waves. Tests with an actual line instead of an artificial line show that the kicks in

the polar relay resulting from the home pole-changer are negligible, as illustrated in No. 588 of Fig. 18, but that the outgoing line current is rounded off as much as in sets that have artificial lines. Therefore, it is not lack of balance that causes the flux in the No. 5-U coil and the rounding off of the outgoing wave. It is, perhaps, the leakage flux in the No. 5-U coil which affects both the line and artificial line sides equally, if the balance is exact.

As a further illustration of the conclusion that the No. 5-U coil has effect in rounding off the outgoing waves No. 465, No. 495 and No. 533 of Fig. 32 can be compared. All three are records made on the previously mentioned 140-mile, No. 8 B. W. G. iron wire simplex circuit, and trace No. 1 is the line side of No. 5-U coils, No. 2 is the artificial line side of No. 5-U coil, and No. 3 is the polar relay circuit. The distant common key was open in all three, the home polar key sending and the other two keys were closed. The peaks of the outgoing waves are rounded off in No. 465, which is the regular bridging quadruplex. They are sharp in No. 495 which is a skeleton resistance quadruplex mentioned above and are also sharp in a regular quadruplex with 500-ohm resistances instead of a No. 5-U coil, as illustrated in No. 533.

In a quadruplex of either bridging or differential type and in the differential duplex, it is readily apparent that the relays which are in the line differentially, that is with one coil in the line and one in the artificial line, act as transformer to some degree. This follows because the two windings have a common core, and current in one winding cannot fail to generate current in the other winding. The extent of this action has not been definitely determined.

Two separate No. 5-U retardation coils were also tried in a quadruplex with one winding of each connected in circuit and the other winding standing open, on the 140-mile No. 8 B. W. G. iron simplex. The result is shown in No. 536. It was not possible to work this quadruplex, because it took too long for the current waves to build up and die out in the retardation coils. The result of the home polar key sending is shown in No. 535, which is plain explanation of the failure of the circuit to telegraph. Trace No. 1 is the line side coil, No. 2 is the artificial line coil and No. 3 is the polar relay. The home key causes wide variation in the current in the home polar relay. These two records disprove the theory that the No. 5-U coil is a retardation coil only.

Modification of the outgoing wave is necessary for circuits such as the bridging duplex is designed for, that is single wires and simplexes, and for these perhaps some suitable retardation coil and condenser can be designed for insertion between the pole-changer and the line relay. The ideal design would be inductive to home sending and non-inductive to received signals. The vacuum tube may solve the problem.

In comparison of bridging and differential duplexes it is seen that the received line waves are practically equal and alike in shape in both, if used on the same circuit and with the same voltage. A question is, which makes more efficient use of this wave? The polar relay has its coils in series on the standard bridging duplex. One coil of this relay would require twice as much current in order to have equal force. The net operating current in a differential set is the difference between the line and artificial line current and can be considered as acting in one coil only of the polar relay. If this net operating current is greater than the bridging set polar relay current multiplied by 2, it has greater force than the

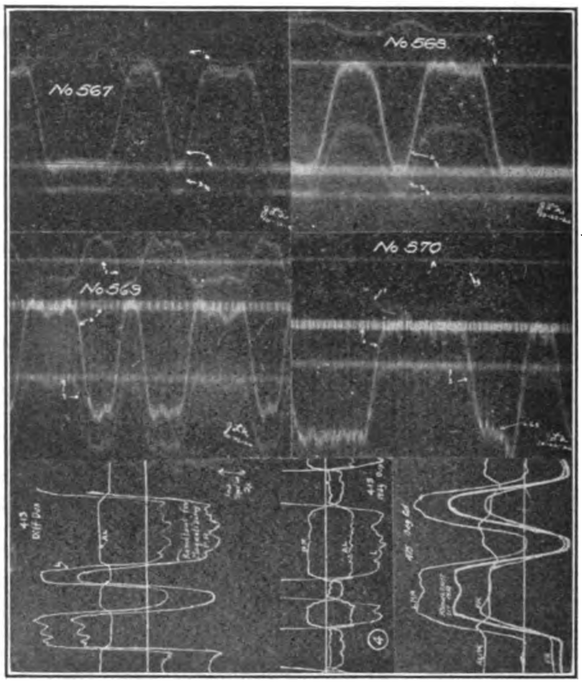

Fig. 35

latter. Tracings from oscillograms Nos. 413 and 415 are given in Fig. 35, and clearly indicate that the differential relay net operating current of No. 413 is more than twice the polar relay current of No. 415. From the records taken it appears that the bridging polar relay does not get as much force as the line coil of a differential set, due to the divided circuit between the No. 5-U coil and polar relay, both of which share the line wave. Therefore, the differential probably makes more efficient use of the line wave than does the bridging duplex.

Polar Relay Speed of Reversal

The quadruplex depends for its success upon the important fact that the fluctuations in the line current due to the insertion and removal of resistance in the distant station main battery, are not distinguishable to the ear in their effect upon the polar relay and its local sounder. The fluctuation is generally set at a 3 to 1 ratio, that is, the current is three times as great

when the distant neutral key is closed and the resistance cut out as when it is open with the resistance in. In some cases the ratio of 4 to 1 is used. In a bridging quadruplex the bridging relay current will be 16 or 17 milliamperes with the distant neutral key closed and 5 to 6 with it open. The polar relay must and does follow the distant polar key without recording this 5 to 16-milliampere variation. Tests were made to demonstrate this, using the circuit of Fig. 33, with the result given in oscillograms No. 355 and No. 356 of Fig. 34. The key circuit was 150 milliamperes, the polar relay was 30 milliamperes and the sounder circuit, 325 milliamperes in No. 355. In No. 356 the polar relay current was reduced to 10 milliamperes. The distance *a-b* in both represents the reversal time of the polar relay armature when the key closes. The interval *c-d* is the reversal time when the key opens. There is no difference noticeable in the *a-b* intervals of the two records, and, likewise, very little difference in the *c-d* intervals of the two, which verifies what is known from listening tests.

Defects of Quadruplex

The neutral side of a quadruplex depends upon increase and decrease of line current strength and should be independent of the direction of the current. One weakness of the standard quadruplex is that the neutral relay is not independent of the reversals of line current which are produced by the operation of the polar side of the circuit. Means are necessary to overcome the resulting opening of the neutral side local sounder circuit when the current reverses in the neutral relay. The present standard of the Western Union Telegraph Company appears to be a development of the Gerrett Smith bridging condenser plan in combination with the Diehl "bug trap" repeating sounder. With the "bug trap" the contact point is the back-stop of the neutral relay armature, and therefore, this armature may, in fact, leave its front stop when a current reversal takes place, and if it pulls up again without striking the back contact, no false signal results. The bridging condenser holding circuit includes a coil on the neutral relay, which gives the armature a pull, due to the condenser charging current that occurs with change of line current, and this pull assists in keeping the armature from striking the back contact during current reversal.

The present design of neutral relay has the holding coils mounted above the line coils, and the armature is extended up to the pole faces of these coils. This results in a comparatively slow or sluggish relay due to armature inertia, and while fast enough for hand sending, for which it was designed, it is too slow for fast hand-operated sending machines or "Vibroplex" use, commonly called "bug" sending.

The standard Western Union bridging quadruplex has the polar relay bridged across the line and artificial line terminals of the No. 5-U coil with its two coils in parallel, and has one winding of the neutral relay in the line and the other in the artificial line. The current readings of small Fig. A of Fig. 29 indicate the steady current values which are with all keys closed, 16 milliamperes in the polar relay and 52 milliamperes, the difference between 56 and 4, in the neutral relay, which is net operating current in one coil of the latter. The 16 milliamperes in the polar relay with coils in parallel are equivalent to 16 milliamperes in one coil, if the same force were applied to one coil only as is the case with the neutral relay. The neutral relay, therefore, has a marginal advantage of 36 milliamperes acting in one coil, over the polar relay due to being in the line. Oscillograms, as well as direct-current measurements, confirm the above advantage claim as shown in the tracing of Fig. 35, at the bottom of the page, traced from oscillogram No. 475, using one base line for all three waves of current, on a bridging quadruplex on the 140-mile, iron wire simplex. On this tracing the difference between the line and artificial line current has been plotted and is marked "Resultant in N. R.," showing that the neutral relay net operating current apparently is greater than the polar relay current.

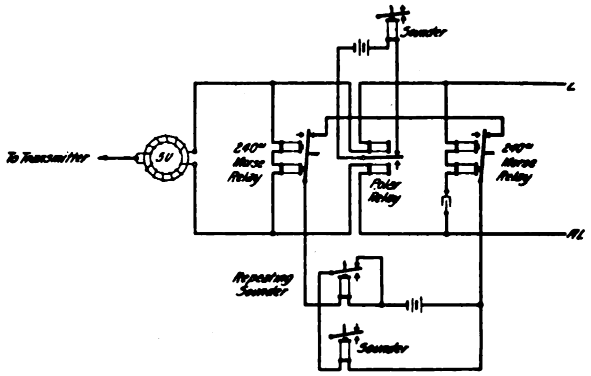

Fig. 36—Reverse Quadruplex

Reverse Quadruplex

The polar side of a standard bridging quadruplex is believed to be weaker than a differential duplex, because of smaller current margin, and in the endeavor to strengthen it, advantage was taken of the apparent higher current in the line, and the positions of the polar relay and the neutral relay exchanged, placing the polar relay differentially in the line and the neutral relay across the No. 5-U coil.

The neutral relay was next separated into two parts, consisting of two standard 240-ohm Morse relays, No. 4-C, one in the bridge and the other in the holding condenser circuit, with the result shown in Fig. 36 called a "reverse" quadruplex, which is a faster quadruplex than the one with the standard neutral relay. This novel arrangement of the holding relay in series with the holding condenser and separate from the neutral relay, functions when the line current reverses, due to the distant pole-changer operating, and pulls up the holding relay and opens the neutral relay local circuit at the moment it tends to close when the

line current reverses. Tests were made with a reverse type quadruplex on the 140-mile iron wire simplex with the distant station sending on the polar key, first with the holding relay contact short-circuited and not functioning, and second with the neutral relay contact short-circuited and not functioning, but with the holding relay operating. The first is No. 543, of Fig. 34, in which trace No. 1 is line current, trace No. 2 is bridge relay current and trace No. 3 is the neutral relay local circuit. The relation of waves in traces Nos. 1 and 3 shows the time at which the neutral relay releases, due to line current reversal. The second case is No. 545, in which trace No. 1 is line current as in No. 543, trace No. 2 is holding relay circuit, which has the condenser in series with it, and trace No. 3 is the neutral relay local circuit. The break in the local circuit here comes at practically the same place in the line wave that the circuit tends to close in No. 543.

Actual results confirm the fact that these two circuits function in harmony, producing a practicable "bug trap." The repeating sounder is retained as in the standard quadruplex. The closure of the neutral relay local circuit with operation of the distant neutral key, is illustrated in No. 544 as trace No. 3, in which the line current is trace No. 1, and the bridging relay, in this case the neutral relay, is trace No. 3. This type of quadruplex will follow fast "bug" sending on the neutral side.

The second weakness of a quadruplex is lack of accurate artificial line balance, and a means of determining the accuracy of the balance better than the standard milliammeters is greatly needed for both duplex and quadruplex. It is not possible with the milliammeters to distinguish between a balance on an artificial line and the balance obtained by the use of an actual line. The results as observed on the Morse and as recorded by the oscillograph, show there is a very decided difference in the best artificial line balance and the actual line balance. A meter with a beam of light instead of a swinging coil and pointer, based on the oscillograph vibrator idea, is suggested. The undulator for multiplex circuits perhaps may be advantageously used with ordinary Morse duplexes.

Terminal Resistance Unbalance

The terminal resistances, which are in the main battery taps as protection from short circuits at the pole-changer contacts, are a third detrimental factor in the quadruplex and also in the duplex, but more so in the quadruplex. In Fig. 29 it is seen that the current in the negative battery is 60 milliamperes with all keys closed, and is 137 milliamperes when the distant polar key is open. The 137 milliamperes cause a greater potential drop across the battery protection resistance and result in less effective voltage to the artificial line, which upsets the balance to a considerable extent as seen in the resultant neutral relay wave of No. 475 traced in Fig. 35. This causes the current to be light with the keys all closed and heavy when the distant polar key is open. If the home polar key is open, the conditions of heavy and light are the reverse, that is, the current is heavier when the distant polar key is closed than when it is open. The effect is apparent in the polar relay, and although less noticeable, is very detrimental in the neutral relay by reducing the working margin to the extent of the difference between the light and heavy current. The remedy suggested is to use No. 2-A or similar circuit breakers in place of terminal resistance, and use generators or battery with negligible internal resistance.

Cause of Light and Heavy Writing

A fourth factor detrimental to good quadruplex results and also to duplex working, is the tendency for the polar relay to write heavy when the home polar key is closed and to write light when it is open, caused by the distant office pole-changer armature travel being too great, or its speed of travel too slow. This action is independent of and in addition to the terminal resistance unbalance. If all keys are closed, there is no current in the line. Assume that the distant pole-changer now opens; *i. e.* leaves the negative battery, and is held midway between contacts a definite length of time, that is, on neither positive nor negative battery. The home battery and the stored energy of the line and equipment will be the only forces acting. The current values that existed the instant previous to opening the key, were comparatively small, there was no current in the line, and the magnetic inertia tends to keep the current flowing as it was, hence no great effect is noted, not enough to throw or start the home polar relay armature. Now, let the distant pole-changer strike the back contact which is positive battery, and the line current will jump up perhaps to 100 milliamperes and promptly throw over the polar relay armature. If the pole-changer is now "opened" again without making contact on either polarity, half the voltage causing the 100-milliampere line current will be cut off, the current will quickly decay, and the home battery will weaken the current in the polar relay and tend to start it in its reversal. If the pole-changer now closes, *i. e.* makes contact on negative battery, the line current will become zero and the polar relay will be reversed by the home battery. In this explanation the point is that when the distant pole-changer leaves the negative or closed pole, the effect is negligible until the positive pole is in action; this tends to lengthen the marking signal at the polar relay, and the movement of the pole-changer from the positive or open pole toward the closed or negative pole, causes quick action in the polar relay, tending to make it close. Thus, the effects are to lengthen marking signals by quick closing and delayed opening.

Assume both the pole-changers to be on the open or positive battery and the line current zero. Now,

if the distant pole-changer opens and is held midway between contacts a moment, the spacing signal at the home station will continue. When the pole-changer is placed on closed or negative battery, the line current will jump up to about 100 milliamperes and the home polar relay will be reversed to the marking contact. If the distant pole-changer is now held open again, the 100 milliamperes will be cut off and the home battery also will tend to weaken the current in the home polar relay. When the open or positive pole is again put in action at the distant pole-changer, the force necessary to complete the action of reversing the home polar relay will be slight and the result prompt. In this explanation it is seen that slow or delayed movement of the distant pole-changer from the positive or open pole to the negative, tends to make the marking signal slow to begin, and the delayed action in closing again tends to cut off the marking signal almost as soon as if no delayed action occurred. Thus, by delaying the start and not delaying the end of a marking signal, the signal is made shorter, which is the reverse of the condition with the home polar key closed. The result is heavy signals with the home polar key closed and light signals with the home polar key open. The remedy is close adjustment of the pole-changer, but this will not change the terminal resistance unbalance trouble.

From oscillogram No. 455 of Fig. 32, which is the record of line current as trace No. 1, bridge relay as trace No. 2, and holding relay as trace No. 3, on the 140-mile iron wire simplex, it would appear, at first glance, beyond expectation for the relays of a quadruplex to follow such apparently senseless waves. The experiments so far made encourage the belief that it is not impossible. In the first place, if an artificial line as good as an actual line is obtained, half the problem is solved. The terminal resistance unbalance, pole-changer travel unbalance and unnecessary relay inertia are other factors which are capable of improvement.

Inductive Disturbance in Telephones from Differential Sets

It is the experience on the New York Central Lines that differential operation on some classes of circuits causes considerable induction in adjacent circuits, in some cases interfering to a serious extent with the operation of telephone circuits carried on the same pole lines. The increasing number of multiplex printer circuits which are differential-operated increases the disturbances.

Bridging duplexes do not seem to cause appreciable difficulty of this nature, but the speed of operation of the bridging sets may not be as high as with differential working. Certain tests have shown that the differential system is satisfactory from an induction standpoint on paralleling telephone circuits when used on composited phantom wires, that is, on the Morse legs of two pairs making up a phantom of which each pair gives one Morse circuit; also on Morse circuits made up of each of two wires which form a long-distance telephone pair. It is the intention, therefore, to use the differential system on composited wires and the bridging system on simplex and single wires, on the New York Central Lines. However, it is apparent from some oscillograms taken that bridging sets can be speeded up when used on composited circuits by removing the condensers and coils in the Morse legs of the composite sets, but because the efficiency of the differential is higher and the polar relay in it gets more current at lesser operating voltages, it seems preferable to use differential on composited circuits. The lessened voltage results in lessened disturbance in the telephone branch of the circuit.

Oscillograms No. 458 and No. 459 of Fig. 37 show the outgoing and incoming waves on a circuit made up of a 280-mile loop of simplexed telephone lines equipped with Western Electric Company straight step-up selectors, consisting of two so-called "high-resistance" simplexes—one 140-mile No. 8 B. W. G. iron pair, and the other 140-mile No. 9 B. & S. copper pair—connected together without repeaters at the junction point. That is, the circuit was arranged with two duplex sets at Indianapolis, Ind., on two simplexes to Springfield, Ohio, where the simplexes were tied together without repeaters. This permitted simultaneously recording both outgoing and incoming waves at Indianapolis. The sharpness of the differential waves in trace No. 1 of No. 459 is noticeable, compared with the more rounded wave of trace No. 1 of No. 458, which is the bridging duplex. The duplex sets used were standard Western Union instruments, installed according to that company's specifications. The simplex coils were Western Electric Company No. 46-A with No. 34-B non-inductive resistances added between the No. 46-A coil and the line.

A number of records were made to see if a differential set at one end of a line and a bridging set at the other had any effect upon the operation of the circuit, but no detrimental effect could be noted. One point noted was that the received wave is the same shape in both differential and bridging circuits. The sharp peak of the outgoing differential set is absorbed by the line, upon simplex and composites at least, which were the kind of circuits tested. This is illustrated in trace No. 2 of No. 567 of Fig. 35 for bridging set, and No. 568 for differential set, which were taken on a low-resistance phantom composite loop of Fig. 11. These two circuits were 140 miles each, No. 9 A. W. G. copper dispatching and message lines. Points *a* and *b* of Fig. 11 were connected at the Bellefontaine end, making a loop, Indianapolis to Bellefontaine and return. All the composite and telegraph equipment was cut off at Bellefontaine.

The effect of the grounded capacity and half No. 5-AA retard coils in the Morse legs was noted by cutting

them out and taking No. 569 bridging and No. 570 differential, other conditions being the same as Nos. 567 and 568. In Nos. 567 and 568 trace No. 1 is the polar relay current, and trace No. 2 is the line current at the receiving station. In Nos. 568 and 570, No. 1 is the artificial line current and No. 2 the line current at the receiving station. Comparison of Nos. 567 and 569, bridging sets, indicates that the half No. 5-AA coils and six-microfarad condensers, as used in No. 567, appreciably round off the waves and slow up the circuit, and that they can be dispensed with and yet obtain fairly smooth waves as in No. 569. Comparison of Nos. 568 and 570, differential sets, indicates

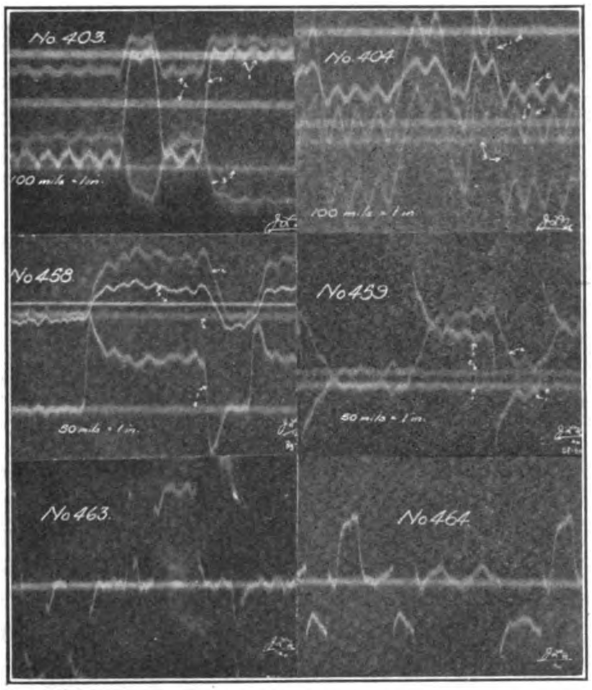

FIG. 37

the necessity of having these coils, as No. 570 has rather sharp waves. No. 568 indicates that the differential waves are rounded out enough to prevent induction.

An interesting exhibit is shown in No. 463 and No. 464, which are records made on two working multiplex printing telegraph circuits. The No. 463 was taken at Indianapolis on a Chicago-Louisville multiplex wire, and No. 464 was at Indianapolis on an Indianapolis-Cincinnati multiplex wire. It is evident that No. 464 was being operated as a differential set, and it is probable that No. 463 was also, but as the record was made at the middle of the line, the waves are somewhat rounded off. No. 464 illustrates why induction is heard on telephone circuits from these multiplex circuits with their sharp waves.

Records No. 403 and No. 404 of Fig. 37 show the result of 25-cycle induction from a single-phase trolley line on duplexes, used on a composite leg of a No. 9 A. W. G. copper, low-resistance phantom, Indianapolis to Cincinnati, 110 miles. The trolley line parallels the railroad from Indianapolis, 40 miles toward Cincinnati. The No. 403 is with duplexes with 500-ohm resistance in place of the No. 5-U coils. Trace No. 1 is line current, trace No. 2 is artificial line and trace No. 3 is the polar relay. The No. 404 is the same as No. 403, but has No. 5-U coils, which greatly amplify the induced waves, but the net operating current in the polar relay is about the same in both. The effect of an induced wave, if it should occur at a time of zero current in the polar relay, might cause false signals, with the No. 5-U coil set.

The investigations indicate that the one-microfarad condenser in duplex and quadruplex sets at the vertex of the No. 5-U retard coil, has but slight bearing on the wave shape of the circuit and is chiefly advantageous as a spark eliminator at the pole-changer contacts. Six microfarads were tried without noticeable effect.

It is noted in the bridging quadruplex that the holding condenser current affects a loop consisting of the condenser, the holding relay, line relay and bridge relay. No effect of it can be detected in the line, the artificial line or in the No. 5-U coil.

The "bulge" of the polar relay current is noted in both the duplex and quadruplex. In the quadruplex this is confined to the above mentioned loop consisting of the holding condenser circuit, line relay and bridge relay. In the duplex it is seen to a limited extent in the line and in the No. 5-U coil.

TELEGRAPH TRANSMISSION DISTANCES

On the N. Y. C. Lines three hundred miles are about the maximum a single No. 8 B. W. G. iron wire is used for single Morse in through service or semi-local service. If all way offices are cut in, the average distance is 150 miles. On iron wire block simplexes the distances are about the same as above. While the line wire resistance is halved in a block simplex, the leakage is increased and the simplex coil resistance is added, resulting in the wire being about as good as a single wire of similar material and gage for the same length. There are so few single copper wires in the N. Y. C. Lines in telegraph use, that no experience with them can be related. As indicated in the discussion of single Morse operation on page 51, these iron wires prove unsatisfactory for local way wires with many offices in wet and foggy weather. Iron wire should not be considered for main lines with heavy traffic because of the rapid deterioration from smoke.

Duplexes are used on the average for about one railroad division which is 150 miles, on high-resistance simplexes of No. 8 B. W. G. iron wire. Copper wire simplexes or composites, No. 9 A. W. G., high-resistance type, are good for more than this length but seldom for two divisions. Low-resistance copper simplexes or composites, No. 9 A. W. G., are good for 300 miles. Copper wire, No. 8 B. W. G., is used in simplex composite and phantom composite, low-resistance type, for 500 miles.

Quadruplexes are good for about 300 miles on single No. 9 A. W. G. copper wire; block simplex, No. 8 B. W. G. iron, for 150 miles; high-resistance No. 8 B. W. G. iron simplexes, 100 miles; copper No. 9 A. W. G. simplexes, high-resistance type, to perhaps 150 miles; and on low-resistance type 200 miles. Very little data regarding quadruplexes on composite circuits are available. This combination is seldom used. The above data are for circuits without repeaters.

Comparison of the telegraph transmission qualities of different gages and kinds of wires and types of circuits have been made and are recorded in Fig. 38. No. 616 is the record of a bridging duplex, first with the distant station sending, which is the trace above the base line, and second with the home station sending, which is the trace below the base line. The wire is a No. 9 A. W. G. copper single wire between Indianapolis and Mattoon, Ill., distance 134 miles. In this territory there is very little cable—hardly enough to

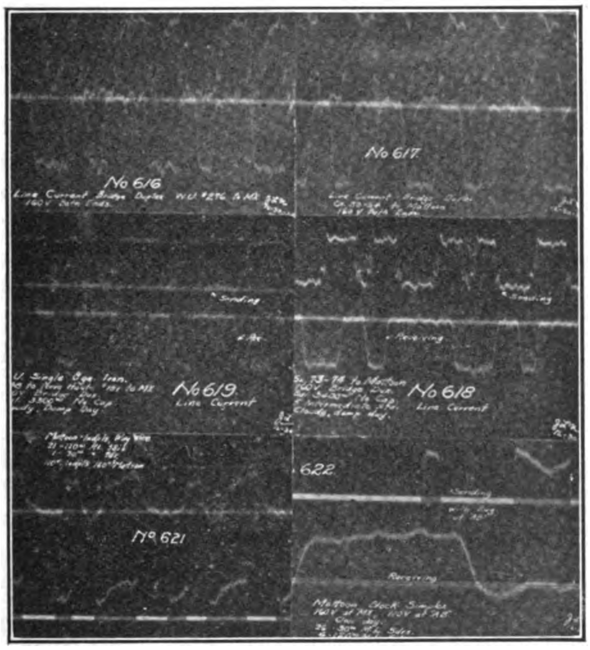

Fig. 38

be considered in such short duplexes. No. 617 is the same duplex on one side of a composited phantom between the same two points and recorded similarly. The circuit is No. 9 A. W. G. copper, low-resistance type simplex on the dispatcher's circuit, which is one side of a phantom. It will be seen that the current is greater on this than on the single copper wire and the wave shape is practically the same, indicating that the circuit is about as fast in dry weather as the single wire.

The duplexes were next moved to the No. 8 B. W. G. iron wire between the same points with the result given in No. 619. No. 618 is the result on a No. 8 B. W. G. iron wire simplex circuit between these points, low-resistance type, and indicates as good a dry-weather cuit as the single iron wire No. 619.

cirFig. 18 gave the record of the way Morse wire on this division of the railroad, taken at the time when it was equipped with 120-ohm main line sounders. This wire was later made one side of the station-to-station block telephone circuit and simplexed for the way-station Morse service, at which time it was equipped with 30-ohm main line sounders. The record of its present transmission is No. 622. The Western Union way wire in this territory is No. 8 B. W. G. iron, with 120-ohm main line sounders, and is recorded in No. 621. The block simplex has more current but has 30 offices, whereas the W. U. Co. way wire has but 22 offices.

Telephone Transmission Distances

Experience indicates that the railroad service requires ten-mile telephone transmission or better for the dispatching, message and long-distance lines. Dissatisfaction results if the equivalent in miles of standard cable is much greater than this. This shows that the railroad demands better transmission than is considered satisfactory in commercial service. From the standpoint of practical results and satisfaction to the users of the railroad telephone lines the following has been noted:

No. 8 B. W. G. iron for long-distance lines should not exceed 50 miles of line; for way-station message telephone lines using railroad telephones, 75 miles.

No. 9 A. W. G. copper for long-distance lines should not exceed 150 miles; for dispatching and message lines, 225 miles; for phantoms composited, 150 miles.

No. 8 B. W. G. copper for long-distance lines should not exceed 300 miles without repeaters.

The above figures are based upon average conditions such as obtain upon the New York Central Lines, and take into consideration that some of the P. B. X. stations are a considerable distance from the P. B. X. which limits the transmission distance because of the loop losses. Circuits are frequently used of longer distances than the above but at a sacrifice in efficiency and with some annoyance to the users.

The railroad telephones as used on dispatching and message lines produce considerably more volume of transmission than standard P. B. X. station telephones, and therefore have greater transmission distance, which experience indicates is 30 per cent greater than the standard P. B. X. stations for equal volume of received transmission.

The author wishes to express his cordial appreciation of the extensive assistance rendered by Mr. John L. Niesse, Telegraph & Telephone Engineer, C. C. C. & St. L. Ry., in making the oscillograms and for other assistance in preparing data for this paper, and to Professor C. Francis Harding, Head, School of Elec. Eng., Purdue University, for the use of the oscillograph.

Heat Losses in the Conductors[1] of Alternating-Current Machines

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WITH the increase in the capacity of alternating-current generators, it has become more and more important to determine the exact relation between the heat developed in any conductor and the currents that it and other neighboring conductors carry. Solutions for the distribution of alternating current within conductors that are embedded in open rectangular slots have been obtained for a number of cases. The methods of attack and the results obtained have heretofore involved trigonometric and hyperbolic functions of real angles. For this reason the work has been unnecessarily complicated, and its scope considerably cramped. Had the investigators used hyperbolic functions of *complex* angles, they would have accomplished more with much less effort. These hyperbolic functions of *complex* angles are such a powerful tool in the solution of this current distribution problem that the author feels fully justified in presenting this discussion of their application, even though many of the results have been obtained before.

At the outset it should be observed that certain assumed ideal conditions are necessary in order to bring the problem within the range of our mathematical ability.[2] Briefly these conditions are (1) that an element of current in the slot produces a uniform parallel magnetic field above itself and none below it; (2) that the current density along any line parallel to the bottom of the slot is constant; (3) that the resistivity of the conductor is uniform throughout, even though more heat is developed in some portions than in others; (4) that voltages in the end connections due to leakage flux are the same for every element of the conductor.

1. The first assumption can be shown to be exactly true in the hypothetical case of an infinitely long rectangular conductor placed in an infinitely deep rectangular slot of the same width which is cut into an infinite medium of infinite permeability.

2. The second assumption is probably sufficiently accurate, except when conductors that carry different currents are placed side by side in the same slot, a condition which we will not consider.

3. The heat conductivity of copper is so high that the temperature of any one conductor is probably nearly uniform, except in the case of extremely deep conductors, and the resistivity would thus not vary appreciably from point to point. In the case of multiple layer coils, however, there may be such a difference in the amount of heat developed in successive layers that it may be desirable to use different resistivities for different layers. In order to carry out this refinement in the calculations, a considerable practical knowledge of the principles of heat radiation in this problem would be necessary, and the final result would probably be obtained by making successive approximations.

4. The leakage flux about the end connections is of course much less than that about the embedded portion of the coils, and is distributed in a totally different manner. Any rational consideration of the effect of this flux would lead to considerable complication in the mathematical analysis. Thus for the sake of simplicity—a feeble reason, no doubt—it is not considered. It is probable, however, that in a great many instances this coil-end leakage is of relatively minor importance.

The best test of the value of the mathematical deductions based on the foregoing assumptions lies in experimental research. The little evidence that we now have seems to confirm the theory within reasonable limits of error, and it is hoped that a more extended investigation, which is being carried on, will prove conclusive.

To the author, it seems nearer the physical reality to say that the increased heat loss in a conductor carrying alternating rather than direct current is caused by a redistribution of current over the cross-

1. An abstract of this paper was presented before the Research Division of the Electrical Engineering Department at the Massachusetts Institute of Technology, April 13, 1920. The author's attention was first directed to this method of analysis by Dr. A. E. Kennelly to whom great credit is due especially on account of the extensive tables he has published from which numerical computations may readily be made: "Tables of Complex Hyperbolic and Circular Functions," A. E. Kennelly.

See also:

"Eddy Currents in Large Slot-Wound Conductors," A. B. Field, Annual Convention, A. I. E. E., 1905.

"Current Distribution in Armature Conductors," W. V. Lyon, *Electrical World*, July 12, 1919.

Since this present analysis was made, Mr. R. E. Gilman has presented at the Annual Convention, A. I. E. E., 1920, a paper entitled "Eddy Current Losses in Armature Conductors." This paper of Mr. Gilman's, although he uses real quantities exclusively, is more complete in one respect than the one here presented in that he considers the case of a laminated conductor with a finite number of strands.

2. Both A. B. Field and R. E. Gilman assume these ideal conditions in the derivation of their formulas.

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

section of the conductor.[3] This redistribution is due to the electromotive forces set up by the magnetic flux *within* the conductor itself. Flux that is wholly without the conductor links all elements of it equally, produces the same voltage in each element, and thus does not affect the current distribution.

Consider any conductor lying in the midst of others, as shown in cross-section in Fig. A. Further, consider any element of this conductor of depth $d\,x$ situated x centimeters from the bottom of the conductor. With a solid conductor the length of this element should be taken only as the length of the armature core. The allowance that need be made for ventilating ducts, and more particularly for end turns, can only be determined by. considerable experimental research. With finely laminated conductors, the current density is constrained to be the same in, at least, the length of a half turn, and the length of the element is then that of a half turn.

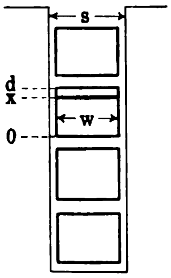

FIG. A

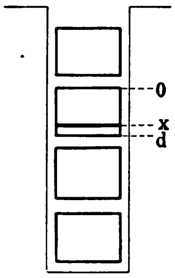

FIG. B

The net voltage acting on the element is the sum of the resistance drop and the voltage drop due to flux linkages. The former is $l_1\,\rho\,c$; where l_1 is the length of the core with solid conductors, or a half turn with finely laminated ones, ρ is the resistivity and c is the current density—all in c. g. s. units. The voltage drop due to flux linkages may be divided into two parts; that due to flux set up by the current in the conductor itself, and that due to flux set up by current in other conductors in the slot *below* the one we are considering. Any current above this conductor produces flux that links all elements of it *alike*, and induces the *same* voltage in each. The manner in which a *given* current is distributed in any conductor below the one in question does not affect the amount of flux linking the element considered. Furthermore any flux due to these latter currents that passes across the slot above the conductor we are considering links all of its elements alike, and, since it produces the same voltage in each, need not be considered. Thus the total flux linking the element in question that need be taken into account is:

$$\varphi = 4\,\pi\,i_b\,\frac{d-x}{s}\,l_2 + \int_x^d \left\{ 4\,\pi \int_0^x w\,c\,\partial\,x \right\} \frac{l_2\,\partial\,x}{s}$$

The first term is the flux, linking the element due to a total current of i_b below the conductor of which the element is a part. The second term is the flux from x to d due to the current within the conductor itself from zero to x. l_2 is the length of the armature core, s is the width of the slot, and w that of the conductor.

The total voltage drop that need be considered is:

$$e = l_1\,\rho\,c + \frac{\partial}{\partial\,t} \left\{ 4\,\pi\,i_b\,\frac{d-x}{s}\,l_2 + \int_x^d \left\{ 4\,\pi \int_0^x w\,c\,\partial\,x \right\} \frac{l_2\,\partial\,x}{s} \right\} \qquad \textbf{(A)}$$

In a solid conductor this voltage drop is the same for every element, and $\frac{\partial\,e}{\partial\,x}$ will thus be zero. Also l_1 and l_2 are equal. Differentiating e and dividing by l_2 gives:

$$\rho\,\frac{\partial\,c}{\partial\,x} - \frac{4\,\pi}{s}\,\frac{\partial\,i_b}{\partial\,t} - \frac{4\,\pi}{s} \int_0^x w\,\frac{\partial\,c}{\partial\,t}\,\partial\,x = 0 \qquad \textbf{(B)}$$

With finely laminated conductors whose laminations are joined at the beginning and end of each half turn, the same result is obtained except that l_1 and l_2 are not equal. Then:

$$\frac{l_1}{l_2}\,\rho\,\frac{\partial\,c}{\partial\,x} - \frac{4\,\pi}{s}\,\frac{\partial\,i_b}{\partial\,t} - \frac{4\,\pi}{s} \int_0^x w\,\frac{\partial\,c}{\partial\,t}\,\partial\,x = 0$$

With finely laminated conductors whose end turns are untwisted and in which the laminations are continuous throughout a whole turn or a whole coil, the voltage in a half turn of any element is as given above. (Equation **A**). The sum of these half-turn voltages between the points at which the laminations are joined together must be the same for each lamination. This sum will consist of a number, n, of resistance drops, and an equal number of voltage drops due to flux linkages. The resultant drop is

$$e = n\,l_1\,\rho\,c + \frac{\partial}{\partial\,t} \sum_1^n 4\,\pi\,i_b\,\frac{d-x}{s}\,l_2$$

$$+ n\,\frac{\partial}{\partial t} \int^d \left\{ 4\,\pi \int_0^x w\,c\,\partial\,x \right\} \frac{l_2\,d\,x}{s} = 0$$

The current i_b, below the conductor of which the half-turn element is a part, is not the same for the different half-turn elements. Nevertheless, it is a simple matter to compute the average value of this quantity, *viz.*, $1/n \sum_1^n i_b$ for any arrangement of conductors. It is, of course, not necessary that the component i_b's should be in phase with each other. This computation is subsequently shown in detail. We will represent this average value of i_b by i_0. If the entire voltage for this element be divided by $n\,l_2$ and then differentiated with respect to x, we have:

$$\frac{l_1}{l_2}\,\rho\,\frac{\partial\,c}{\partial\,x} - \frac{4\,\pi}{s}\,\frac{\partial\,i_0}{\partial\,t} - \frac{4\,\pi}{s} \int_0^x w\,\frac{\partial\,c}{\partial\,t}\,\partial\,x = 0$$

3. Others prefer to say that the increased heating is due to the eddy currents produced by the magnetic flux within the conductor. Either description is permissible.

In the case of finely laminated conductors that are twisted in the end connections so that the top lamination of one half turn becomes the bottom lamination of the next half turn, a similar equation may be derived. When the end turn is twisted in passing from one coil side to the next, the flux within the conductor linking the half-turn element of one side has already been given. (Equation **A**). The flux linking the next half turn of this element is, (Fig. B):

$$\rho = 4\,\pi\, i_b \frac{x\, l_2}{s} + \int_0^x \left\{ 4\,\pi \int_x^d w\, c\, \partial x \right\} \frac{l_2\, \partial x}{s}$$

The first term is the flux from zero to x due to a current of i_b below this conductor. The second term is the flux from zero to x due to current from x to d within the conductor itself. The second term may be rewritten in this way:

$$\int_0^x 4\,\pi \left\{ \int_0^d w\, c\, \partial x - \int_0^x w\, c\, \partial x \right\} \frac{l_2\, \partial x}{s}$$

The voltage drop in this half-turn element becomes:

$$e = l_1\, \rho\, c + \frac{\partial}{\partial t} \left\{ 4\,\pi\, i_b \frac{x\, l_2}{s} + \int_0^x 4\,\pi \int_0^d w\, c\, \partial x \,.\, \frac{l_2 \partial x}{s} - \int_0^x 4\,\pi \int_0^x w\, c\, \partial x \,.\, \frac{l_2\, \partial x}{s} \right.$$

$\int_0^d w\, c\, \partial x$ is the entire current in the conductor of which the element is a part. Represent this current by i. Differentiate e with respect to x and divide by l_2. We have:

$$\frac{l_1}{l_2}\, \rho\, c + \frac{4\,\pi}{s} \frac{\partial\, i_b}{\partial\, t} + \frac{4\,\pi}{s} \frac{\partial\, i}{\partial\, t} - \frac{4\,\pi}{s} \int_0^x w \frac{\partial\, c}{\partial\, t}\, \partial\, x = 0 \qquad \textbf{(C)}$$

Thus in every case that we shall discuss, the following equation may be written:

$$\rho \frac{\partial\, c}{\partial\, x} - \frac{\partial}{\partial\, t} \frac{4\,\pi\, i_0}{s} - \frac{i\, \partial}{\partial\, t} \frac{4\,\pi}{s} \int_0^x w\, c\, \partial\, x = 0 \;[4]$$

ρ is the resistivity in the case of solid conductors, and is the resistivity multiplied by the ratio of the length of a half turn to the length of the core in the case of infinitely laminated conductors. c is the instantaneous current density in amperes per square centimeter along a line x centimeters from the bottom of the conductor. s is the width of the slot and w, that of the conductor. The first term is the differential of the resistance drop per centimeter in any element. The second term is the differential of the voltage per centimeter due to the flux produced by other currents in the same slot. As we shall see, i_0 is determined by the arrangement of the conductors and the currents they carry. The third term is the differential of the voltage per centimeter due to the flux produced by current within the conductor itself below the element considered. If the currents vary sinusoidally with the time, the differential operator $\frac{\partial}{\partial\, t}\cdot$ may be symbolically represented by $j\, \omega$; $j = \sqrt{-1}$, $\omega = 2\,\pi\, f$ where f = frequency.

The equation may now be written in the complex or vector form:

$$\frac{\partial\, \underset{\cdot}{c}}{\partial\, x} - j \frac{4\,\pi\, \omega}{\rho\, s}\, I_0 - j \frac{4\,\pi\, \omega}{\rho\, s} \int_0^x w\, \underset{\cdot}{c}\, \partial\, x = 0 \qquad \textbf{(1)}$$

Differentiating a second time gives:

$$\frac{\partial^2\, \underset{\cdot}{c}}{\partial\, x^2} = j \frac{4\,\pi\, \omega}{\rho\, s}\, w\, \underset{\cdot}{c}$$

or:

$$\frac{\partial^2\, \underset{\cdot}{c}}{\partial\, x^2} = \alpha^2\, \underset{\cdot}{c} \qquad \textbf{(2)}$$

where

$$\left.\begin{aligned} \alpha^2 &= j \frac{8\,\pi^2\, w\, f}{\rho\, s} \\ \text{or} \quad \alpha &= \sqrt{\frac{8\,\pi\, w\, f}{\rho\, s}} \;\underline{/45^\circ} \end{aligned}\right\}$$

The solution of equation (**2**) may be written in the form

$$\underset{\cdot}{c} = \underset{\cdot}{A} \cosh \alpha\, x + \underset{\cdot}{B} \sinh \alpha\, x \qquad \textbf{(3)}$$

This is a vector equation for the root-mean-square current density at a point x centimeters from the bottom of the conductor. The constants of integration $\underset{\cdot}{A}$ and $\underset{\cdot}{B}$ are vector quantities and are usually determined by the current in the conductor considered and by the vector I_0 in equation (**1**). Substitution of equation (**3**) in equation (**1**) shows that:

$$\underset{\cdot}{B} = \alpha / w\, I_0$$

If the depth of the conductor is d centimeters, the current in it is

$$I_1 = \int_0^d w\, \underset{\cdot}{c}\, \partial\, x$$

from which it follows that:

$$\underset{\cdot}{A} = \frac{\alpha}{w} \left\{ \frac{I_1}{\sinh \alpha\, d} - I_0 \tanh \frac{\alpha\, d}{2} \right\}$$

Therefore, the general solution for the vector current density may be written:

4. An equation of this sort applies only to the conductor in which the current density is a continuous function with respect to x, such as is the case with solid or finely laminadet conductors. When the laminations have appreciable depth the current density changes abruptly as we pass from one lamination to the next. The effect of this is that the vector constant i_0 is different in successive laminations. A comparison of equations (**B**) and (**C**) shows that twisting the end connections reverses the effect of the current, i_b, below the conductor we are considering.

$$c = \frac{1}{w\,d}\left\{\frac{I_1\,\alpha\,d\cosh\alpha\,x}{\sinh\alpha\,d} - I_0\,\alpha\,d\tanh\frac{\alpha\,d}{2}\cosh\alpha\,x + I_0\,\alpha\,d\sinh\alpha\,d\right\} \qquad (4)$$

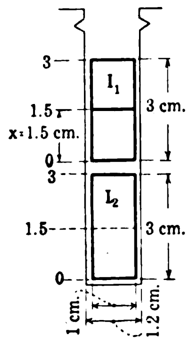

FIG. 1

A numerical calculation is helpful. Consider the case of two solid rectangular conductors situated as shown in Fig. 1. The 60-cycle currents are each 1000 amperes but the lower current leads the upper by 60 degrees as would be the case in some of the slots of a three-phase fractional pitch winding. As we shall presently see $I_0 = I_2$ in this case.

ρ = 2100 c. g. s. units of resistance
w = 1 cm.
s = 1.2 cm.
d = 3 cm.
f = 60 cycles

$$\alpha\,d = 3\sqrt{\frac{8\,\pi^2 \times 1 \times 60}{2100 \times 1.2}}\ \underline{/45^\circ}$$
$$= 4.11\ \underline{/45^\circ}$$

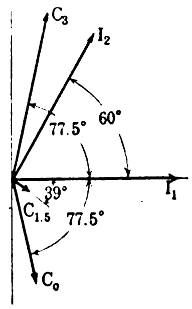

FIG. 2—CURRENT DENSITIES IN UPPER CONDUCTOR

Referred to I_1 the current densities are:

$C_0 = 1620\ \underline{/-77.^\circ 5}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ \underline{/\quad}$

$C_{1.5} = 305\ \underline{/-39.^\circ}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ \underline{/\quad}$

$C_3 = 2490\ \underline{/77.^\circ 5}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ /$

$$\alpha\,x = 2.06\ \underline{/45^\circ}$$
$$\sinh\alpha\,d = 9.12\ \underline{/166.^\circ 4}$$
$$\tanh\frac{\alpha\,d}{2} = 1.11\ \underline{/1^\circ.41}$$
$$\sinh\alpha\,x = 2.24\ \underline{/84.^\circ 1}$$
$$\cosh\alpha\,x = 2.03\ \underline{/82.^\circ 7}$$

If we choose I_1 along the horizontal, *i. e.*, with zero phase:

$$I_1 = 1000\ \underline{/0^\circ}\ ,\ I_0 = 1000\ \underline{/60^\circ}$$

$$c_{1.5} = \frac{1}{1 \times 3}\Big\{(1000\ \underline{/0^\circ} \times 4.11\ \underline{/45^\circ} \times 2.03\ \underline{/82.^\circ 4} \div 9.12\ \underline{/166.^\circ 4}) - (1000\ \underline{/60^\circ} \times 4.11\ \underline{/45^\circ} \times 1.11\ \underline{/1.^\circ 41} \times 2.03\ \underline{/82.^\circ 7}) + (1000\ \underline{/60^\circ} \times 4.11\ \underline{/45^\circ} \times 2.24\ \underline{/84.^\circ 1})\Big\} = \frac{1}{1 \times 3}\Big\{915\ \underline{/-39.^\circ 0} - 923\ \underline{/189.^\circ 1} + 923\ \underline{/189.^\circ 1}\Big\}$$

$$c_{1.5} = 305\ \underline{/-39.^\circ 0}$$
$$c_0 = 1620\ \underline{/-77.^\circ 5}\ .$$
$$c_3 = 2490\ \underline{/77.^\circ 5}$$

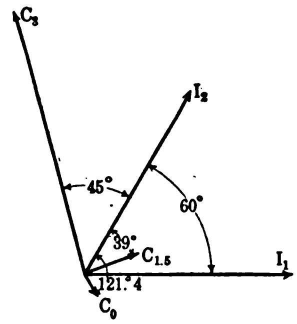

FIG. 2A—CURRENT DENSITIES IN LOWER CONDUCTOR

Referred to I_2 the current densities are:

$C_0 = 150\ \underline{/-121.^\circ 4}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ \underline{/\quad}$

$C_{1.5} = 305\ \underline{/39^\circ}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ \underline{/\quad}$

$C_3 = 1380\ \underline{/45^\circ}\ \dfrac{\text{amperes}}{\text{sq. cm.}}\ /$

Fig. 2 is the vector diagram showing the current densities at the bottom, middle and top of the conductor, together with the total current in it, I_1, and the current below it, I_2.

The current density at the center, where $\alpha\,x$ equals $\dfrac{\alpha\,d}{2}$, is:

$$c = \frac{I_1}{w\,d}\ \frac{\dfrac{\alpha\,d}{2}}{\sinh\dfrac{\alpha\,d}{2}}$$

It depends only upon the average current density and the angular depth, $\alpha\,d$, and is in no way affected by the position of the conductor in the slot. It is the same for solid and finely laminated conductors.

The current density is nowhere greater than at the top of the conductor, where it is:

$$\varrho_d = \frac{1}{w\,d}\left\{ I_1\,\alpha\,d \coth\alpha\,d + \frac{I_0}{2}\,\alpha\,d\,2\tanh\frac{\alpha\,d}{2}\right\} \tag{5}$$

The ratio of this maximum current density to the average is:

$$\frac{\varrho_d}{\varrho_{av}} = \alpha\,d\coth\alpha\,d + \frac{I_0}{2\,I_1}\,\alpha\,d\,2\tanh\frac{\alpha\,d}{2} \tag{6}$$

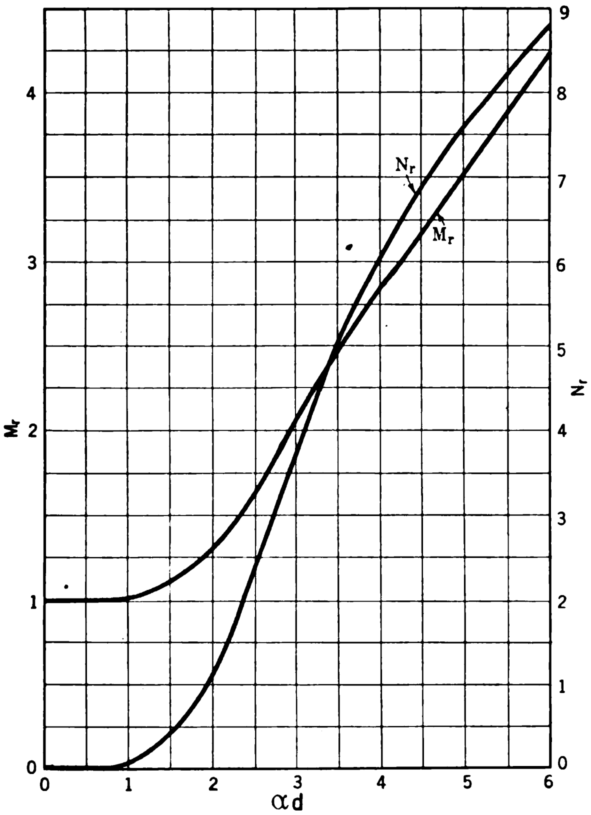

FIG. 3

The complex quantities $\alpha\,d\coth\alpha\,d$ and $\alpha\,d\,2\tanh\frac{\alpha\,d}{2}$ occur in all of the expressions which we shall develop, and thus it will be simpler to represent them by single letters. Hereafter

$$\alpha\,d\coth\alpha\,d = M = M_r + j\,M_x$$

$$\alpha\,d\,2\tanh\frac{\alpha\,d}{2} = N = N_r + j\,N_x$$

In Figs. 3 and 4 the abscissas are the numerical values of $\alpha\,d$ and the ordinates are M_r, M_x, N_r, N_x. The real portions of M and N, *viz.*, M_r and N_r, appear in the expressions for resistance, and the imaginary portions, M_x and N_x, in the expressions for reactance.

The voltage drop per centimeter in the conductor considered due to its own resistance and to all of the leakage flux below its topmost layer is:

$$\rho\,\varrho_d = \frac{\rho}{w\,d}\left\{ I_1\,M + \frac{I_0}{2}\,N\right\} \tag{7}$$

The flux within the conductor due to its own current and all of the current, I_b, below it is:

$$\varphi = \int_0^d \partial x \frac{4\,\pi}{s}\int_0^x w\,\varrho\,\partial x + \frac{4\,\pi\,d}{s}\,I_b$$

On integration the expression for the flux may be written:

$$\varphi = \frac{1}{j\,\omega}\,\frac{\rho}{w\,d}\left\{\left(\frac{I_1}{2} + I_0\right)N + (I_b - I_0)\,\alpha^2\,d^2\right\}$$

The voltage drop per centimeter produced by this flux in each conductor below the one considered is $j\,\omega\,\varphi$, which may now be written:

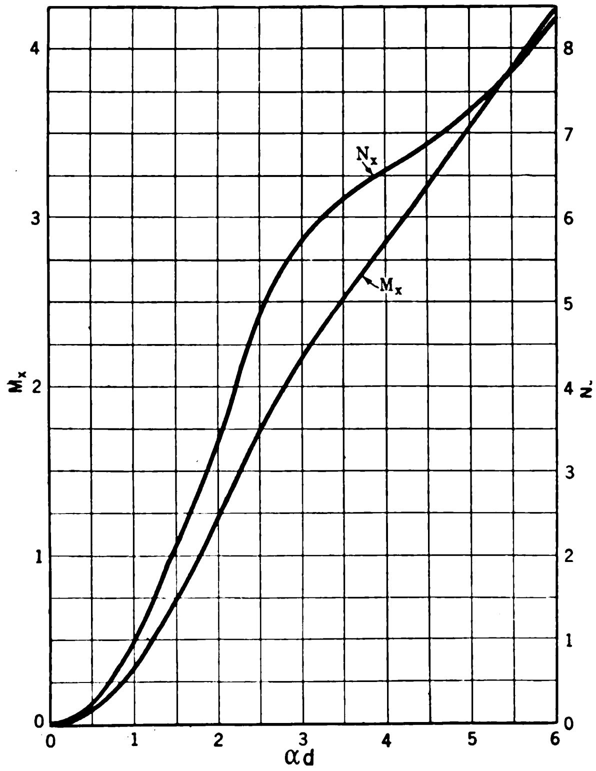

FIG. 4

$$E = \frac{\rho}{w\,d}\left\{\left(\frac{I_1}{2} + I_0\right)N + (I_b - I_0)\,\alpha^2\,d^2\right\} \tag{8}$$

The relations expressed in equations (7) and (8) are very important since their proper combination will give the leakage impedance drop due to resistance and leakage flux within the conductors themselves for any arrangement of solid or infinitely laminated conductors. The reactance due to slot-leakage flux which does not pass through the conductors can be calculated by well-known methods and need not be considered here.

If the equations (7) and (8) are each multiplied by

the length of the core, l, they will apply to the embedded portion of a solid conductor, the true resistance of which is R, and to the half turn of an infinitely laminated one, the true resistance of which is also R. Thus (**7**) and (**8**) may be written:

$$l \rho \, \dot{c}_d = R \left\{ I_1 M + \frac{I_0}{2} N \right\} \qquad \textbf{(7a)}$$

$$l E \quad = R \left\{ \left(\frac{I_1}{2} + I_0 \right) N + (I_b - I_0) \, \alpha^2 d^2 \right\} \qquad \textbf{(8a)}$$

The *additional* voltage produced in all conductors below the one in question by flux within it due to its own current is

$$l E' \quad = R \left\{ \left(\frac{I_1}{2} + I_0 \right) N - I_0 \, \alpha^2 d^2 \right\} \qquad \textbf{(8b)}$$

Having found the vector impedance drop in the conductors of one phase by properly applying equations (**7a**) and (**8a**), the effective resistance and reactance of that phase are determined by dividing this drop by the vector current. The real portion of the result is the effective resistance and the imaginary portion, the effective reactance. This method, however, gives no indication of the distribution of the copper loss among the several conductors of the phase. This may be of considerable importance, especially in the case of solid conductors when the heat developed in the topmost conductor in a slot may be several times that developed in the bottom conductor.

The current through a conductor is non-uniformly distributed on account of flux *within* the conductor. This flux is due only to the current in the conductor itself and to current below it in the slot. Any current above the conductor in question has no effect on the current distribution within it. The heat generated within a conductor depends only upon the manner in which the current is distributed. The current density is completely determined by equation (**1**) and the total current in the conductor itself. For any particular value of I_0 (equation **1**) the heat developed by a given current in the conductor does not depend upon whether I_0 is some particular current or some combination of currents. Thus if it is possible to find the heat loss when I_0 is some particular current, we will have obtained a general expression for the loss in terms of the current in the conductor, I_1, and the constant, I_0, in equation (**1**). The particular case which we will consider is that of a solid conductor carrying a current of I_1 with a total current of I_b below it. The special form of equation (**1**) is then,

$$\frac{\partial \dot{c}}{\partial x} - j \, \frac{4 \pi \omega}{\rho s} I_b - j \, \frac{4 \pi \omega}{\rho s} \int_0^x w \, \dot{c} \, \partial x = 0 \qquad \textbf{(1a)}$$

Thus for this arrangement, $I_0 = I_b$.

The heat loss in the conductor is equal to the total power supplied both to this conductor and to all of those below it less the power supplied to those below it when the conductor is removed from the slot. The addition of the conductor in question increases the power supplied to the lower conductors without increasing the heat loss in them on account of its mutual inductive effect upon them *i. e.*, as some would say, on account of the eddy currents which are produced in it by the total current I_b, below it. The power supplied to the upper conductor is, symbolically, since $I_0 = I_b$

$$I_1 R \left\{ I_1 M + \frac{I_b}{2} N \right\} \qquad \textbf{(See 7a)}$$

This indicates the product of the numerical values of the current, I_1, the voltage applied to the conductor and the cosine of the phase angle between them. Flux above the conductor produces a quadrature voltage and thus does not affect the power. The *additional* power supplied to the conductors below this one is symbolically

$$I_b R \left\{ \left(\frac{I_1}{2} + I_b \right) N - I_b \, \alpha^2 d^2 \right\} \qquad \textbf{(See 8b)}$$

The actual heat loss in the conductor is thus symbolically:

$$I_1 R \left\{ I_1 M + \frac{I_b}{2} N \right\} + I_b R \left\{ \left(\frac{I_1}{2} + I_b \right) N - I_b \, \alpha^2 d^2 \right\}$$

This reduces to:

$$R \left\{ I_1^2 M_r + (I_b^2 + I_1 I_b \cos \theta) N_r \right\} \text{[5]} \qquad \textbf{(9a)}$$

where I_1 and I_b are the numerical values of the currents and θ is the phase angle between them. Therefore the general expression for the heat loss in any conductor, solid or infinitely laminated, is:

$$R \left\{ I_1 M_r + (I_0^2 + I_1 I_0 \cos \theta) N_r \right\} \qquad \textbf{(9)}$$

where I_1 is the numerical value of the current in the conductor, I_0 is the numerical value of the vector constant in the differential equation (**1**), and θ is the phase angle between I_1 and I_0. The ratio of alternating-current to direct-current resistance is thus:

$$K = M_r + \left(\left| \frac{I_0}{I_1} \right|^2 + \left| \frac{I_0}{I_1} \right| \cos \theta \right) N_r \qquad \textbf{(10)}$$

The vertical lines | | indicate that the division is one of numerical values and not of vector values. The first term M_r accounts for the natural non-uniformity of current distribution due to the action of the current upon itself. The second term

$$\left(\left| \frac{I_0}{I_1} \right|^2 + \left| \frac{I_0}{I_1} \right| \cos \theta \right) N_r,$$

accounts for the additional heating produced by the "eddy currents" due to the action of I_0.

5. M_r and N_r are calculated from the data pertaining to the conductor in question and bear no relation to other conductors.

This equation (**10**) enables us to compute the ratio of alternating-current to direct-current resistance for any conductor carrying a specified current and for which a differential equation of the form given equation (**1**) can be written. In the case of solid conductors, the ratio only applies to the embedded portion. The following are the resistance ratios for some of the simpler arrangements of conductors.

1. The heat loss in an open-circuited bar with I_b amperes below it is:

$$\text{heat loss} = R\, I_b^2\, N_r \qquad (\text{equation } \mathbf{9a},\ I_1 = 0)$$

2. The resistance ratio for the pth conductor of a one-coil-side-per-slot bar winding is:

$$K = M_r + [\,(p-1)^2 + (p-1)]\, N_r$$
$$= M_r + (p^2 - p)\, N_r$$

3. The resistance ratio for a one-coil-side-per-slot winding having n layers is:

$$K = 1/n \sum_1^n \ [M_r + (p^2 - p)\, N_r]$$
$$= M_r + \frac{n^2 - 1}{3}\, N_r$$

This is also the ratio for the lower coil side of any bar winding having n layers. The upper coil side has no effect on the resistance of the lower coil side.

4. The resistance ratio for the upper coil side of a two-coil-side-per-slot fractional pitch winding having n layers per coil side reduces to:

$$K = M_r + \left(\frac{4\, n^2 - 1}{3} + n^2 \cos\theta \right) N_r$$

θ is the phase angle between the currents in the upper and lower coil sides.

By combining this with the ratio just preceding, we obtain the resistance ratio for a coil, one side of which is above a coil side carrying a current which differs in phase by θ.

The hottest conductor is the one at the top of the coil side which has beneath it current of the same phase. The fact that, with solid bar windings, the heat developed is not uniformly distributed throughout the winding may be no inconsiderable argument against their use.

5. Our method of attack enables us to obtain a simple solution for the relation between the currents in a double squirrel-cage winding. Neglect the effect of the end rings. In this case the constant of integration, A, in equation (**3**) is determined by the fact that the resistance drop in the lowest element of the upper bar is the same as the impedance drop in the lower bar due to its resistance and to all of the leakage flux which does not link any portion of the upper bar. The vector equation for the current density in the upper bar may be written:

$$\dot{c} = \frac{I_2\, \dot{Z}_2}{\rho} \cosh \alpha\, x + \frac{I_2\, R_1}{\rho}\, \alpha\, d \sinh \alpha\, x$$

$I_2\, \dot{Z}_2$ is the vector impedance drop in the lower bar per centimeter;[6] ρ and R_1 are respectively the resistivity and the true resistance per centimeter of the upper bar whose depth is d centimeters. α is calculated for the upper bar.

The vector current in the upper bar is:

$$I_1 = \frac{I_2\, \dot{Z}_2}{R_1}\ \frac{\sinh \alpha\, d}{\alpha\, d} + I_2 \cosh \alpha\, d - I_2$$

The process of calculating the heat loss in the upper bar by substitution in equation (**9a**) is much simplified if we let

$$P = \frac{m\, Z_2}{R_1} \cos(\theta_2 + \beta) + n \cos \delta$$

and

$$Q = \frac{m\, Z_2}{R_1} \sin(\theta_2 + \beta) + \sin \delta$$

where:

$$\dot{Z}_2 = Z_2 \,/\underline{\theta_2}\,; \quad \frac{\sinh \alpha\, d}{\alpha\, d}{}^{7} = m \,/\underline{\beta}\,;$$
$$\cosh \alpha\, d = n \,/\delta$$

The expression for the loss in the upper bar is:

$$I_2^2\, R_1\, \{\, [(P-1)^2 + Q^2\,]\, M_r + P\, N_r\, \}$$

This method of solution for the relation between the currents in a double squirrel cage should prove of considerable value in any analysis of the design of such windings.

Finely laminated windings may be of three types: Those in which the laminations are joined at the ends of each half turn; those in which they are joined at the ends of each turn; and those in which the laminations are continuous throughout a single coil. The first is like a solid bar winding except that, as noted previously, the real resistivity of the copper should be multiplied by the ratio of the length of the half turn to the length of the core. The resistance ratio then applies to the whole winding and not to the embedded portion solely. The resistance ratios for the second type depend upon whether the end turn between the coil sides is untwisted or twisted. The resistance ratio for the third type depends upon whether the end turns are untwisted, twisted on one side only, or twisted on both sides. One considerable advantage of continuous laminations is that the heat developed is the same in all of the conductors.

6. Type two: End turn untwisted. The arrangement of the coil sides is shown in Fig. 5. The heavy line across the conductors indicates the same lamination. The current, I_2, below the upper coil side may be in phase with the current above it or differ from it by 60 or 90 degrees. The differential equation of the

6. $I_2\, Z_2$ is the voltage drop due to resistance and flux that does not link the upper bar.

7. See Table IV, Tables of Complex Hyperbolic and Circular Functions.

form (1) applying to this case for the pth layer from the bottom is:

$$2\,\rho\,\frac{\partial ç}{\partial x} - j\,\frac{4\,\pi\,\omega}{s}\,\left\{\,2\,(p-1)\,I_1 + I_2\,\right\}$$
$$-\,j\,\frac{4\,\pi\,\omega}{s}\;2\int_0^x w\,ç\,\partial x = 0$$

Comparing this equation (1) shows that the vector constant I_0 equals $(p-1)\,I_1 + \frac{I_2}{2}$; $I_2 = n\,I_1\,\underline{/\theta}$,

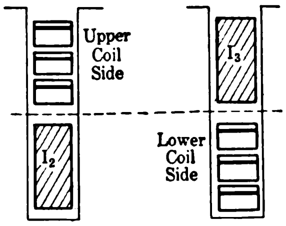

FIG. 5

n is the number of layers in the coil side and θ the phase angle between the currents in the upper and lower coil sides.

Making this substitution, equation (9) reduces to:

Heat loss $= R\,I_1^2\,\{\,M_r + [p^2 - p + n\,(p - 1/2)\cos\theta + n^2/4]\,N_r\,\}$

The resistance ratio for the entire coil is one-nth of the summation of this expression from $p = 1$ to $p = n$. It reduces to:

$$K = M_r + \left(\frac{7\,n^2 - 4}{12} + \frac{n^2}{2}\cos\theta\right) N_r$$

7. Type three: End turns untwisted. In this case the heat developed is the same in each conductor. The differential equation now becomes:

$$2\,n\,\rho\,\frac{\partial ç}{\partial x} - j\,\frac{4\,\pi\,\omega}{s}\sum_1^n \{2\,(p-1)\,I_1 + I_2\,\}$$
$$-\,j\,\frac{4\,\pi\,\omega}{s}\;2\,n\int_0^x w\,ç\,\partial x = 0$$

In this case $I_0 = \frac{n-1}{2}\,I_1 + I_2$. Making this substitution in equation (10) gives the resistance ratio for the whole coil.

$$K = M_r + \left(2\,\frac{n^2 - 1}{4} + \frac{n^2}{2}\cos\theta\right) N_r$$

8. Type two: End turns twisted. When the end turns are twisted on one side only the top laminations in one coil side become the bottom laminations of the other coil side in corresponding layers. See Fig. 6. The lines across the layers trace the positions of one continuous lamination—type three. In type two, however, the laminations are joined at the beginning and end of each turn. The differential equation which applies to the pth layer is:

$$2\,\rho\,\frac{\partial ç}{\partial x} - j\,\frac{4\,\pi\,\omega}{s}\,I_2$$
$$+\,\frac{\partial}{\partial x}\,j\,\frac{4\,\pi\,\omega}{s}\,\{\,(p-1)\,I_1\,(d-x)$$
$$+\,(p-1)\,I_1\,x\,\} - j\,\frac{4\,\pi\,\omega}{s}\left\{\int_0^x w\,ç\,\partial x\right.$$
$$\left.+\int_d^x w\,ç\,\partial x\right\} = 0 \qquad (11)$$

This readily reduces to:

$$\frac{\partial ç}{\partial x} - j\,\frac{4\,\pi\,\omega}{s\,\rho}\left(\frac{I_2}{2} - \frac{I_1}{2}\right)$$
$$-\,j\,\frac{4\,\pi\,\omega}{s\,\rho}\int_0^x w\,ç\,\partial x = 0$$

Notice that the mutual effect of the layers upon each other is eliminated, by twisting the end connection (third term (11)). The resistance ratio is thus the same for each turn. It is independent of the current in the lower coil side, but it does depend upon the number of layers in the coil side.

$$K = M_r + \frac{n^2 - 1}{4}\,N_r$$

9. Type three: End connections twisted on one side only. The differential equation of the form (1) is:

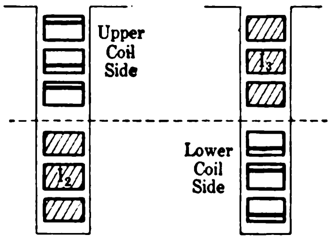

FIG. 6

$$2\,n\,\rho\,\frac{\partial ç}{\partial x}$$
$$+\,\frac{\partial}{\partial x}\,j\,\frac{4\,\pi\,\omega}{s}\,I_2\,\{\,(d-x) + x + (d-x) + \ldots\ldots$$
$$+\,\frac{\partial}{\partial x}\,j\,\frac{4\,\pi\,\omega}{s}\,I_1\left\{\begin{array}{l}(d-x) + 2\,x + 3\,(d-x) + \ldots\ldots \\ +\,x + 2\,(d-x) + 3\,x + \ldots\ldots\end{array}\right\}$$
$$-\,j\,\frac{4\,\pi\,\omega}{s}\,\{\,n\int_0^x w\,ç\,\partial x + n\int_d^x w\,ç\,\partial x\,\}$$

The third term of this equation is always zero, but the second term may or may not be. It is thus apparent that there are two cases to be considered, *viz.*, when the number of layers is even and when it is odd. If n is even the second term is zero and the equation reduces to:

$$\frac{\partial \underset{\cdot}{c}}{\partial x} - j \frac{4 \pi \omega}{s \rho} \left(- \frac{I_1}{2} \right) - j \frac{4 \pi \omega}{s \rho} \int_0^x w \underset{\cdot}{c} \, \partial x = 0$$

Notice that this equation is independent of the number of layers and the current in the lower coil side. This arrangement of an even number of continuously laminated layers whose end turns are twisted on one side only gives the smallest resistance ratio of any of the cases considered.

$$K = M_r - 1/4 \, N_r$$

From the forms of M_r and N_r this is readily shown to be the M_r for a conductor one-half as deep. This same condition of current distribution is obtained by having an even number of laminated conductors side by side in the slots if the end connections are twisted on one side only. The resistance ratio is then independent of the number of layers in the coil. If n is odd, the differential equation reduces to:

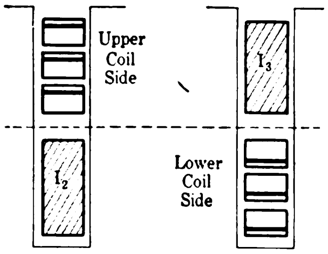

FIG. 7

$$\frac{\partial \underset{\cdot}{c}}{\partial x} - j \frac{4 \pi \omega}{s \rho} \left\{ \frac{I_2}{2 n} - \frac{I_1}{2} \right\} - j \frac{4 \pi \omega}{s \rho} \int_0^x w \underset{\cdot}{c} \, \partial x = 0$$

The resistance ratio is now:

$$K = M_r$$

This ratio is the same as in the case of a *single* solid conductor of the *same* depth, whereas if there are an even number of layers the ratio is the same as for a single solid conductor of one-half the depth of the laminated one.

10. Type three: End connections twisted on both sides (See Fig. 7). The differential equation of the form (1) is:

$$2 n \rho \frac{\partial \underset{\cdot}{c}}{\partial x} + \frac{\partial}{\partial x} j \frac{4 \pi \omega}{s} I_2 (d - x) n + \frac{\partial}{\partial x} j \frac{4 \pi \omega}{s} I_1 \left\{ \begin{array}{l} (d - x) + 2 x + 3 (d - x) \\ \qquad + \ldots\ldots \\ + x + 2 (d - x) + 3 x \\ \qquad + \ldots\ldots \end{array} \right\} - j \frac{4 \pi \omega}{s} \left\{ n \int_0^x w \underset{\cdot}{c} \, \partial x + n \int_d^x w \underset{\cdot}{c} \, \partial x \right\} = 0$$

This reduces to:

$$\frac{\partial \underset{\cdot}{c}}{\partial x} - j \frac{4 \pi \omega}{s \rho} \left(\frac{I_2}{2} - \frac{I_1}{2} \right) - j \frac{4 \pi \omega}{s \rho} \int_0^x w \underset{\cdot}{c} \, \partial x = 0$$

The resistance ratio is:

$$K = M_r + \frac{n^2 - 1}{4} N_r$$

It is independent of the current in the lower coil side. Notice that this is the same ratio as was obtained for case 8.

Enough illustrations of the method and the simplicity of its application have been given. There follows a numerical calculation of the resistance ratios for a given arrangement of conductors of various types. The winding data are: Three-phase with four slots per pole per phase; coil pitch of 10 slots; two turns per coil; conductors 1.5 cm. deep; length of embedded portion and of end turns the same; frequency 60 cycles, the ratio of width of copper to width of slot, 0.6; resistivity, 2100 c. g. s. units.

For solid conductors:

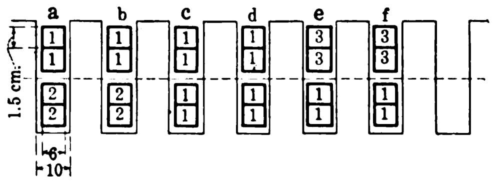

FIG. 8

$$\alpha d_s = 1.5 \sqrt{\frac{8 \pi^2 \times 60 \times 0.6}{2100}} \; \underline{/45^\circ}$$

$$= 1.74 \; \underline{/45^\circ}$$

From curve

$$M_r = 1.20$$
$$N_r = 0.73$$

For laminated conductor:

$$\alpha d = 1.5 \sqrt{\frac{8 \pi^2 \times 60 \times 0.6}{2 \times 2100}} \; \underline{/45^\circ}$$

$$= 1.23 \; \underline{/45^\circ}$$

From curve

$$M_r = 1.05$$
$$N_r = 0.20$$

The arrangement of the conductors of one phase before one pole is shown in Fig. 8. The resistance ratios for phase one are given in the following table for the various cases considered.

TABLE I

SOLID CONDUCTORS	RATIO
Lower coil sides (slots c, d, e & f)	1.93*
Upper " " (" a and b)	6.31*
" " " (" c and d)	7.77*
Entire winding including end turns	2.75†

INFINITELY LAMINATED CONDUCTORS, TYPE 1.

Lower coil sides (slots c, d, e & f)	1.25
Upper " " (" a and b)	2.45
" " " (" c and d)	2.85
Entire winding	1.95

INFINITELY LAMINATED CONDUCTORS, TYPE 2.

Untwisted (slots c and d)	1.85
" (" a, b, e and f)	1.65
" (entire winding)	1.75
Twisted (entire winding)	1.20

INFINITELY LAMINATED CONDUCTORS, TYPE 3.

Untwisted (slots c and d)	1.80
" (" a, b, e and f)	1.60
" (entire winding)	1.70
Twisted in one end connection (entire winding)	1.005
Twisted in both end connections (entire winding)	1.20

*Embedded portion.

†The ratio of the heat developed in the top conductor of slots, b or c to that developed in the bottom conductor is as $\frac{9.96}{1.20}$ or as 8.3 to 1.

This may be a very important consideration, even more than the resistance ratio for the entire winding.

Leakage Reactance Volts. As previously stated, the entire leakage impedance due to resistance and slot leakage flux lying wholly within the conductors themselves may be computed by the proper combination of equations (**7a**) and (**8a**). This method offers little or no advantage when calculating the resistance. It has been shown that in the case of solid bar winding I_0 equals I_b, (equation **8a**). Thus it is probable that the expressions for reactance are similar to those for resistance except that M_x and N_x would replace M_r and N_r. Such proves to be the case. In the case of laminated conductors, however, there is an added term in the expressions for reactance. Consider the general case of a three-phase fractional pitch winding, a typical arrangement of which is shown in Fig. 8. There will usually be slots in which both coil sides are in the same phase. There will also be slots in which the top coil side is in phase one, for example, and the lower coil side in phase two, together with an *equal* number of slots in which the lower coil side is in phase *one* and the upper coil side in phase three. In the general polyphase case of p phases there will be slots occurring in pairs in which the currents differ in phase by plus and minus π/p radians. Let us designate these symmetrical pairs as fractional pitch slots and those in which the upper and lower coil sides are in the same phase as full pitch slots. Accordingly there are two fractional pitch and two full pitch slots per pole per phase in the winding illustrated in Fig. 8. Let n be the number of layers per coil side and R the true resistance of the conductors considered

1. Solid conductors: Full pitch slots. Apply equations (**7a**) and (**8a**), but divide by the phase current, I_1, in order to obtain the impedance directly. With solid conductors the coefficient of $\alpha^2\, d^2$ in equation (**8a**) is zero. Let p be the number of any conductor measured from the bottom of the slot. There are $2\,n$ conductors in both layers in the slot.

The vector expression for the impedance is:

$$Z = \frac{R}{2\,n}\left\{ \sum_{1}^{2n} \left(M + \frac{p-1}{2}\, N \right) + \sum_{1}^{2n} (p-1)\,(1/2 + p - 1)\, N \right\}$$

The first term is the summation of the resistance drops (equation **7a**) divided by the current; the second term is the summation of the reactive drops per ampere produced in each of the $(p-1)$ conductors below the pth conductor (equation **8a**) by the flux within the latter.

This reduces to:

$$Z = R\left\{ M + \frac{4\,n^2 - 1}{3}\, N \right\}$$

The resistance is the real portion of this expression and the reactance the imaginary portion. Thus:

$$r = R\left\{ M_r + \frac{4\,n^2 - 1}{3}\, N_r \right\}$$

$$x = R\left\{ M_x + \frac{4\,n^2 - 1}{3}\, N_x \right\}$$

2. Solid conductors: Fractional pitch slots (taken in pairs as described). The expression for the impedance reduces to

$$\begin{aligned} Z = \frac{R}{2\,n} \Bigg\{ & \sum_{1}^{n} \left[M + \left(\frac{p-1}{2} + n\,\underline{/\theta} \right) N \right] \\ & + \sum_{1}^{n} \left[M + \frac{p-1}{2}\, N \right] \\ & + \sum_{1}^{n} (p-1) \left[\frac{1}{2} + (p-1) + n\,\underline{/\theta} \right] N \\ & + n \sum_{1}^{n} \left[\frac{\underline{/-\theta}}{2} + (p-1)\,\underline{/-\theta} + n \right] N \\ & + \sum_{1}^{n} (p-1) \left[\frac{1}{2} + (p-1) \right] N \Bigg\} \end{aligned}$$

The first two terms are respectively the summations of the resistance drops per ampere (equation **7a**) in the upper and lower coil sides; the third term is the summation of the reactive drops per ampere produced in each of the $(p-1)$ conductors below the pth conductor of the upper coil side (equation **8a**) by the flux within the latter due to its own current and all of that below it in the slot; the fourth term is the reactive drop (equation **8a**) in the lower coil side due to the flux within the coil side above it which carries

a current having a relative phase angle of $\angle{-\theta}$; the last term is the summation of the reactive drops per ampere produced in each of the $(p-1)$ conductors below the pth conductor of the lower coil side (equation **8a**) by the flux within the latter.

This reduces to:

$$Z = R\left\{ M + \left(\frac{5\,n^2-2}{6} + \frac{n^2}{2}\cos\theta \right) N \right\}$$

The resistance is:

$$r = R\left\{ M_r + \left(\frac{5\,n^2-2}{6} + \frac{n^2}{2}\cos\theta \right) N_r \right\}$$

The reactance is:

$$x = R\left\{ M_x + \left(\frac{5\,n^2-2}{6} + \frac{n^2}{2}\cos\theta \right) N_x \right\}$$

This expression is general for both fractional and full pitch slots. For the latter θ equals zero.

3. Finely and continuously laminated conductors (type three) with untwisted end connections. Consider the general case of symmetrical pairs of fractional pitch slots in which the currents in the coil sides lying in the same slot differ in phase by plus and minus θ. R is the true resistance of one coil. In this case

$$I_0 = \frac{n-1}{2} I_1 + \frac{I_2}{2} \ ;$$

where I_2 is the current in the lower coil side.

$$\begin{aligned} Z = \frac{R}{2\,n} & \Bigg\{ 2\sum_1^n \left[M + \left(\frac{n-1}{2\times 2} + \frac{n\angle\theta}{2\times 2} \right) N \right] \\ & + \sum_1^n (p-1) \Bigg[\left(\frac{1}{2} + \frac{n-1}{2} + \frac{n\angle\theta}{2} \right) N \\ & \qquad + \left(p - 1 + n\angle\theta - \frac{n-1}{2} - \frac{n\angle\theta}{2} \right) \alpha^2 d^2 \Bigg] \\ & + n\sum_1^n \Bigg[\left(\frac{\angle{-\theta}}{2} + \frac{n-1}{2}\angle{-\theta} + \frac{n}{2} \right) N \\ & \qquad + \left((p-1)\angle{-\theta} + n - \frac{n-1}{2}\angle{-\theta} - \frac{n}{2} \right) \alpha^2 d^2 \Bigg] \\ & + \sum_1^n (p-1) \Bigg[\left(\frac{1}{2} + \frac{n-1}{2} + \frac{n\angle\theta}{2} \right) N \\ & \qquad + \left(p - 1 - \frac{n-1}{2} - \frac{n\angle\theta}{2} \right) \alpha^2 d^2 \Bigg] \Bigg\} \end{aligned}$$

The first term is the summation of the resistance drops per ampere (equation **7a**) in the upper and lower coil sides. Due to the fact that laminations are continuous the current distribution is the same in each conductor of the coil. Thus the resistance drops are also the same for each conductor. The second, third and fourth terms respectively correspond to the third, fourth and fifth terms in the preceding case.

This reduces to:

$$Z = R\left\{ M + \left(\frac{2\,n^2-1}{4} + \frac{n^2}{2}\cos\theta \right) N + \frac{4\,n^2-1}{12}\,\alpha^2 d^2 \right\}$$

The resistance and reactance are respectively the real and imaginary portions of this expression. Thus:

$$r = R\left\{ M_r + \left(\frac{2\,n^2-1}{4} + \frac{n^2}{2}\cos\theta \right) N_r \right\}$$

$$x = R\left\{ M_x + \left(\frac{2\,n^2-1}{4} + \frac{n^2}{2}\cos\theta \right) N_x + \frac{4\,n^2-1}{12}\,|\alpha|^2 d^2 \right\}$$

$|\alpha|^2$ is the square of the numerical value of α, *viz.*, $\dfrac{8\,\pi^2\,w\,f}{\rho\,s}$.

4. Finely and continuously laminated conductors (type three) with end connections twisted on both sides. Consider the general case of symmetrical pairs of fractional pitch slots in which the currents in the coil sides lying in the same slot differ in phase by θ. Due to the twist in the end connections the current density is the same at points equally distant from the bottom of half of the conductors, and from the top of the other half. The expression for the flux within the conductor has already been given for the first condition. When current density is measured from the top of the conductor, the expression for the flux within it is:

$$\varphi = \frac{4\,\pi}{s} \int_d^0 \partial x \int_d^x w\, c\, \partial x$$

This readily reduces to:

$$\varphi = \frac{1}{j\,\omega}\,\frac{\rho}{w\,d} \left\{ (I_1 + I_0)\,\alpha^2 d^2 - \left(\frac{I_1}{2} + I_0 \right) N \right\}$$

The total flux within the conductor including that produced by the current, I_b, below it is:

$$\varphi_0 = \frac{1}{j\,\omega}\,\frac{\rho}{w\,d} \left\{ (I_1 + I_0 + I_b)\,\alpha^2 d^2 - \left(\frac{I_1}{2} + I_0 \right) N \right\}$$

The voltage produced in every conductor below the one in question by this flux is:

$$E = R\left\{ (I_1 + I_0 + I_b)\,\alpha^2 d^2 - \left(\frac{I_1}{2} + I_0 \right) N \right\}$$

where R is the true resistance of a half turn.

For conductors in which the current density is given for values of x measured from the top, rather than from the bottom, the resistance drop $\rho\, ç$ is that in the bottom element. The flux within this conductor then produces an *additional* voltage in it. In this case

$$I_0 = \frac{I_2}{2} - \frac{I_1}{2}$$

$$Z = \frac{R}{2\,n}$$

$$\Big\{ 2 \sum_1^n \Big[M + \Big(\frac{n \angle\theta}{2 \times 2} - \frac{1}{2 \times 2} \Big) N \Big]$$

$$+ \sum_1^n (p-1) \Big[\Big(\frac{1}{2} + \frac{n \angle\theta}{2} - \frac{1}{2} \Big) N$$

$$+ \Big((p-1) + n \angle\theta - \frac{n}{2} \angle\theta + \frac{1}{2} \Big) \alpha^2 d^2 \Big]$$

$$+ n \sum_1^n \Big[\Big(\frac{\angle -\theta}{2} + \frac{n}{2} - \frac{\angle -\theta}{2} \Big) N$$

$$+ \Big((p-1) \angle -\theta + n - \frac{n}{2} + \frac{\angle -\theta}{2} \Big) \alpha^2 d^2 \Big]$$

$$+ \sum_1^n p \Big[\Big(1 + \frac{n}{2} \angle\theta - \frac{1}{2} + (p-1) \Big) \alpha^2 d^2$$

$$- \Big(\frac{1}{2} + \frac{n}{2} \angle\theta - \frac{1}{2} \Big) N \Big] \Big\}$$

In this expression R is the true resistance of the coil. The terms are written in the same order as in the previous case.

This reduces to:

$$Z = R \; \Big\{ M + \frac{n^2 - 1}{4} \, N + \Big(\frac{7\,n^2 - 1}{12} + \frac{n^2}{2} \cos\theta \Big) \alpha^2 d^2 \Big\}$$

The method of calculating the impedance should now be sufficiently clear. The final equations for the impedance of finely and continuously laminated conductors whose end turns are twisted on one side only are given without showing their detailed construction.

There are two cases to consider,—one with an even number of layers per coil side, and the other with an odd number of layers.

For n, even

$$Z = R \; \Big\{ M - \frac{N}{4} + \Big(\frac{10\,n^2 - 1}{12} + \frac{n^2}{2} \cos\theta \Big) \alpha^2 d^2 \Big\}$$

For n, odd

$$Z = R \; \Big\{ M + \Big(\frac{10\,n^2 - 1}{12} + \frac{n^2}{2} \cos\theta \Big) \alpha^2 d^2 \Big\}$$

The formulas are given in such detail that it must be evident how the effects of unbalanced currents may be calculated. If there are marked harmonics in the currents the heating loss for each harmonic may be calculated as if the others were absent. The resulting loss is the sum of the component losses. The resistance ratios increase with the frequency so that higher harmonics of any considerable magnitude may prove troublesome. For example, if the currents should contain 20 per cent fifth and seventh harmonics, the resistance ratio for the entire winding—solid conductors—would increase from 2.75 as given in Table I to 2.95. This neglects any skin effect in the end turns which would probably be considerable for these harmonics. It also neglects the fact that with higher harmonics there would be a marked magnetic skin effect in the laminations surrounding the conductor which might raise the saturation to such a point that the fundamental assumptions would no longer hold.

The increase in the ratio for the embedded portion only is much more marked. The ratio for the embedded portion of the entire winding as calculated from Table I is

$$\frac{4 \times 1.93 + 2 \times 6.31 + 2 \times 7.77}{8} = 4.49$$

The ratio for the entire embedded portion with harmonics present becomes 6.73. The ratio of the heats developed in top and bottom conductors of slots c or d becomes $\frac{15.8}{1.39}$ or 11.4 when these harmonics are present instead of the value of 8.3 as given in the table.

By making the proper assumptions, this method of analysis allows us to account for the hysteresis and eddy current losses in the armature teeth and core due to the leakage flux, the effect of which we are discussing. Assume that, due to these iron losses, each tube of flux lags behind the net current that is producing it by the same angle, η. If this be the case the reactive drop will lead the resistance drop by $(\pi/2 - \eta)$ radians instead of by $\pi/2$ radians as we have assumed.

Thus $\quad \alpha^2 = \dfrac{8\,\pi^2 f\,w}{\rho\, s} \angle -\dfrac{\pi}{2} - \eta$

and $\quad \alpha = \sqrt{\dfrac{8\,\pi^2 f\,w}{\rho\, s}} \angle \dfrac{\pi}{4} - \dfrac{\eta}{2}$

New values of the complex quantities M and N may be calculated for this value of α and substituted in the expressions for effective resistance and reactance already obtained. Whether or not this method will produce accurate results can only be determined by much experimental research.

SUMMARY OF FORMULAS

SOLID CONDUCTORS

$$\text{Ratio} \quad \frac{\text{Alternating-current resistance}}{\text{Direct-current resistance}}$$

pth conductor from bottom one-coil-side-per-slot bar winding.

$$M_r + p\,(p - 1)\,N_r$$

One-coil-side-per-slot with n layers, or lower coil side with n layers.

$$M_r + \frac{n^2 - 1}{3}\,N_r$$

Upper coil side, n layers, two-coil-side-per slot, fractional pitch.

$$M_r + \left(\frac{4\,n^2 - 1}{3} + n^2 \cos\theta\right) N_r$$

FINELY LAMINATED CONDUCTORS (laminations soldered at beginning and end of each turn) fractional pitch[1]

$$\text{Ratio} \quad \frac{\text{A-C. resistance.}}{\text{D-C. resistance}}$$

End turn untwisted, pth conductor from bottom of upper coil side.

$$M_r + [p^2 - p + n\,(p - 1/2)\cos\theta + n^2/4]\,N_r$$

End turn untwisted, each coil side.

$$M_r + \left(\frac{7\,n^2 - 4}{12} + \frac{n^2}{2}\cos\theta\right) N_r$$

End turn twisted, each coil side.

$$M_r + \frac{n^2 - 1}{4}\,N_r$$

1. Two coil sides per slot, n layers per coil side.

FINELY LAMINATED CONDUCTORS, soldered at the beginning and end of each coil. Ratio of impedance to direct current resistance is given for a pair of coil sides below one of which is current lagging by θ and above the other current leading by θ. n layers per coil side.[2]

End turns untwisted.

$$M + \left(\frac{2\,n^2 - 1}{4} + \frac{n^2}{2}\cos\theta\right) N + \frac{4\,n^2 - 1}{12}\,\alpha^2 d^2$$

End turns twisted both sides.

$$M + \frac{n^2 - 1}{4}\,N + \left(\frac{7\,n^2 - 1}{12} + \frac{n^2}{2}\cos\theta\right)\alpha^2 d^2$$

End turns twisted one side, n even.

$$M - \frac{N}{4} + \left(\frac{10\,n^2 - 1}{12} + \frac{n^2}{2}\cos\theta\right)\alpha^2 d^2$$

End turns twisted one side, n odd.

$$M + \left(\frac{10\,n^2 - 1}{12} + \frac{n^2}{2}\cos\theta\right)\alpha^2 d^2$$

2. In calculating the impedance only leakage flux that lies within the conductors is considered. There are well known methods for calculating the reactance due to other leakage flux.

Carrier Current Telephony and Telegraphy

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Western Electric Co. American Telephone & Telegraph Co.

(*Continued from page 315 of JOURNAL for April, 1921.*)

Repeaters. From the discussion of the transmission characteristics of lines which will be given later in the paper, the very great practical importance of amplifying apparatus at intermediate points on a line employing carrier frequencies will be evident. For this purpose fortunately we have available, first, the vacuum tube, and, second, a large variety of methods of applying this tube which have been developed to a high state of efficiency in connection with the voice frequency telephone repeater. While, as just indicated, the same general considerations apply to repeaters for carrier current circuits as to repeaters on circuits operated at voice frequencies, the conditions peculiar to carrier current operation require that the repeaters for this service differ quite considerably from standard voice frequency repeaters.

In the first place, on a multiplex carrier current circuit a single repeater installation must handle the energy associated with a number of independent conversations. This could be accomplished by making the installation include a number of repeaters in parallel with suitably associated filter combinations, but it is at once obvious that it is much preferable to install but one repeater channel capable of amplifying all the carrier transmission. The requirements for the repeater set are made still more severe by the fact that modulation in the repeater tubes, which tends to increase with the load, introduces disturbing factors in carrier operation which are not serious in ordinary repeater operation. The reason for this is that the combination frequencies resulting from the interaction of the currents in two channels may lie in the frequency

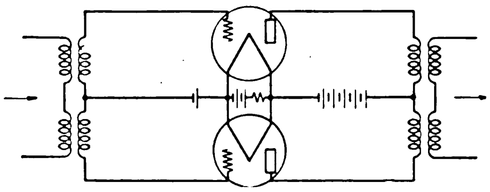

FIG. 21

range of a third, in which case they are transmitted through the selective circuits of that channel and appear as an interfering noise or tone at the subscriber's station. To obtain sufficient energy carrying capacity, and to overcome to some degree this difficulty of intermodulation, we use a number of tubes in parallel in the so-called "push-pull" arrangement. The principle of the push-pull amplifier is shown in Fig. 21.

In this arrangement the input voltage is applied in such a way as to increase the grid voltage of one tube

with respect to its filament at the same time that the grid voltage of the other is diminished. The plates are connected with the output circuit by a differential transformer, so that the useful amplified currents from the two tubes are added, while the more troublesome of the interfering components due to modulation are equal in amplitude and opposite in phase, and are balanced out. Instead of employing tubes in parallel to increase the energy capacity of the set, it would have been possible to have used a single tube of larger energy capacity. The scheme of using a number of tubes operating in parallel was adopted in order to avoid increasing the number of types of tubes in the plant.

In repeater operation at voice frequencies, the amount of amplification which can be secured on a given line and with given types of repeater apparatus is limited by the tendency to "sing." The same is true for repeater operation at carrier frequencies. To reduce the tendency of the repeater to sing, the same methods may be adopted as are employed at the terminals; that is to say, if the same frequencies are used for the transmission in both directions, the lines on either side of the repeater must be balanced and the same general type of repeater circuit used as for voice frequency telephone repeaters (see Fig. 22). If, however, different frequencies are employed for transmission in the two directions, filters may be used to prevent the currents sent out in one direction from passing into the input circuit of the repeater set which receives energy from that direction.

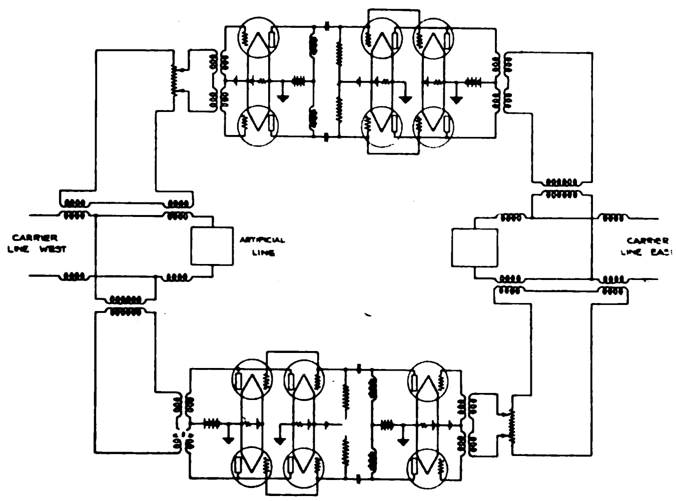

FIG. 22

While the telephone currents at voice frequencies may be amplified in the same repeater along with the carrier currents, it has been found convenient for reasons of plant flexibility to separate voice frequencies from carrier frequencies by line filters similar to those used at the terminals. Due to the fact that the attenuation of voice frequencies is much lower than that of carrier frequencies, it is frequently not necessary to install a voice frequency repeater at all of the points where carrier frequency repeaters are installed. A number of arrangements are illustrated in the sections dealing with commercial systems.

Signaling over Carrier Telephone Circuits. For a carrier telephone channel to form an integral part of an ordinary telephone connection, it is in general desirable to be able to operate the normal signaling mechanism over the channel without the intervention of an operator at the terminals of the carrier section. This is accomplished by two distinct methods in the two types of system employed. In the type where carrier current is transmitted over the line, an auxiliary rectifier tube is associated with the demodulator in such a manner that the incoming carrier current produces in the output circuit of this rectifier a direct current sufficient to maintain a relay in its operated position. When the operator signals, the ordinary 16-cycle ringing current is received at the carrier terminal. This is made to operate a relay, which disconnects the source of carrier current from the modulator, thereby stopping its transmission over the line. As a result, at the distant terminal the relay controlled by the rectified current falls back, causing an ordinary 16-cycle ringing current to be sent out over the connecting line associated with that particular channel.

In the system where the carrier current is suppressed, the 16-cycle ringing current from the low-frequency line operates a relay which applies to the modulator, through the speech circuit, a current of 133 cycles from a vacuum-tube oscillator or other source. This current interacts with the carrier current in the modulator to produce a side band current, differing from the carrier by 133 cycles, which is transmitted to the distant terminal. Here it is demodulated and appears in the voice frequency circuit as a current of 133-cycle frequency. This current operates a relay tuned to this frequency, which in turn serves to send out 16-cycle ringing current over the low-frequency line.

Actual circuit arrangements showing these two methods of signaling are shown in the sections of this paper describing commercial systems.

Telegraph. Carrier current telegraphy is based on the same fundamental principles as carrier current telephony, but in actual operation it employs somewhat different physical arrangements, owing to the differences in the nature of the signals to be transmitted and to the differences between the operating conditions met in the two cases.

In ordinary telegraphy the signaling current consists of a succession of so-called "marking pulses" separated by intervals of zero or oppositely directed current representing spaces. In transmitting telegraph signals over a line by the carrier method, the signaling current, as received from the local telegraph trunk or from a connecting long-distance telegraph line, operates a relay which controls the application of carrier current to the high-frequency line. The usual arrangement is such that high-frequency current of uniform amplitude is sent out during the marking

intervals only. At the receiving terminal this high-frequency current is rectified, generally after amplification, by a vacuum tube. The resulting rectified current operates a relay, which in turn sends signals over the connecting telegraph circuit or loop. Fig. 23 shows a simple, one-way carrier telegraph circuit with one-way direct-current telegraph loops at either end.

It has sometimes been assumed that the only frequency transmitted under these conditions is that of the carrier, and that therefore the only limitation on the frequency intervals between the carriers of adjacent channels is that imposed by the degree of selectivity possible of attainment with actual physical apparatus. That this is not the case is easily seen from a consideration of the building up and decay of current in a sharply resonant circuit. If the time required for the current to build up in such a circuit is comparable with the lengths of the marking and spacing intervals, the high-frequency current will not accurately reproduce the telegraph signals. This causes a rounding off of the signal, or, if it is sufficiently extreme, the signals disappear altogether.

To determine quantitatively the relation between the constants of the selective circuits and the speed and quality of the signals, it is most convenient to regard the problem as a case of modulation. As in telephony it was shown to be necessary to transmit a band of frequencies equal in width to the voice frequency range, similarly in carrier telegraphy it is necessary to transmit a band of high frequencies corresponding to the important frequencies present in the direct-current telegraph signals. An analysis of the ideal current wave representing a succession of telegraph signals reveals the presence of an infinite series of components whose frequencies extend to infinity and whose amplitudes decrease with increasing frequency. Ordinary telegraph circuits transmit only components of comparatively low frequency, with the result that the signals are rounded off. Reasonably good signals are secured, however, if those components are preserved whose frequencies are a few times the fundamental interruption frequency. The upper limit of this essential frequency band varies with different types of apparatus and with different grades of service required, but it is for any one set of conditions roughly proportional to the speed of signaling. For the cases so far met with in practise, it is of the order of 100 or 200 cycles. It follows, therefore, that while a modulated wave, whose envelope approximates ideal telegraph signals, would require the transmission over the line of a very wide band of frequencies, satisfactory operation requires the transmission of a band of frequencies equal only in width to the essential frequency range of ordinary telegraphy. In case of multiplex carrier telegraph operation, the non-essential frequency components are accordingly suppressed by the selective sending circuits, so as to prevent them from interfering with other channels.

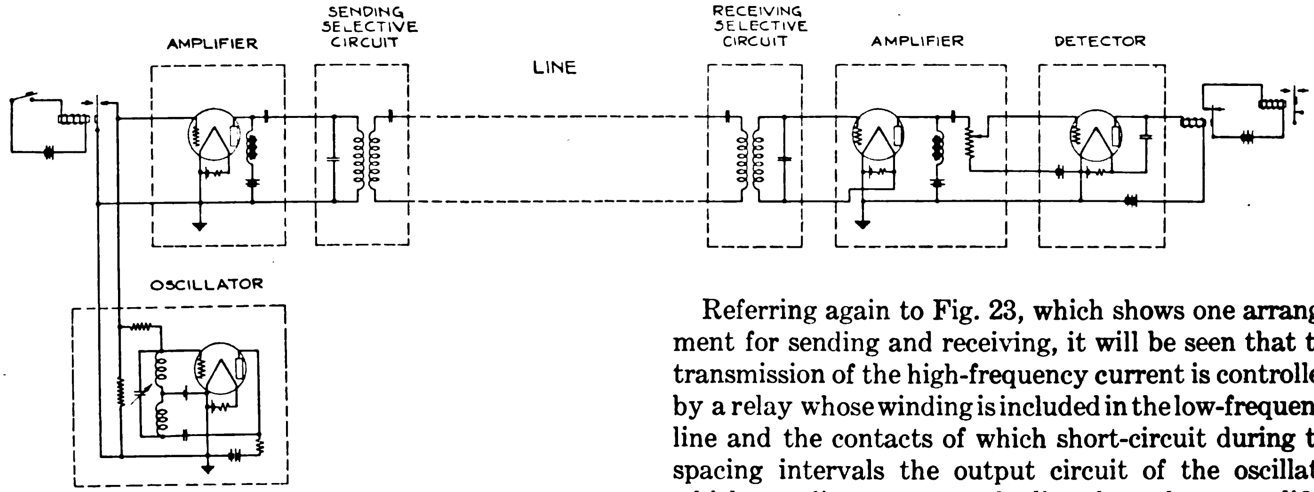

Fig. 23

Referring again to Fig. 23, which shows one arrangement for sending and receiving, it will be seen that the transmission of the high-frequency current is controlled, by a relay whose winding is included in the low-frequency line and the contacts of which short-circuit during the spacing intervals the output circuit of the oscillator which supplies energy to the line through an amplifier. At the receiving terminal the arrangement for demodulation or detection requires some further explanation. The carrier current, after suitable amplification, is applied to the input circuit of a vacuum-tube detector. The grid of this tube is made just sufficiently negative to prevent the flow of current in the plate circuit, which includes the winding of a relay, when no high-frequency current is being received from the line through the amplifier. During the marking intervals a high-frequency alternating potential is applied to the grid, causing a high-frequency pulsating current to flow in the plate circuit and operate the relay which is adjusted so as to be held in the operated position for the duration of the signal. The contacts of this relay control the sending of signals over the connecting telegraph circuit.

Referring to the question of multiplex operation, it may be mentioned that where the carrier frequency is of the order of several thousand cycles, the percentage difference in frequency between the extreme edges of the side band is so small, that it is not so readily possible to design circuits to suppress one of the side bands,

as can be done in the case of telephony. For this reason, the frequency range assigned to a carrier telegraph channel has been twice that of the essential frequency range of the direct-current telegraph channel. As is obvious from previous consideration, the advantages of band filters largely disappear for narrow transmission bands at high frequencies, and in telegraphy it has been found more convenient, for the signaling speed so far met with, to use loosely coupled resonant circuits, such as are shown in Fig. 23.

A frequent condition of two-way operation involves what in ordinary telegraph working is termed "full-

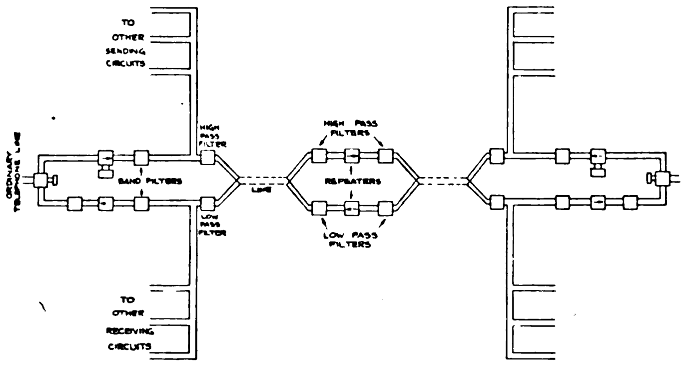

FIG. 24

duplex operation," where the oppositely directed channels are used simultaneously for independent messages. In ordinary telegraphy this full-duplex operation is secured by balanced bridge arrangements which involve at each terminal a close balancing of the actual line by an artificial line. This close balancing at low frequencies is secured by rather close attention of a repeater operator and rather frequent readjustments of the artificial line constants. While it is possible to adapt such an arrangement to the carrier telegraph line, it has not been found economical to do so because of the ease of securing full-duplex operation by the use of different carrier frequencies for the two directions. The extension of this method to multiplex operation is obvious. A very convenient frequency arrangement for carrier telegraphy has been found to be that in which transmissions in one direction occupy a range of frequency from 3300 to 6000 cycles, and those in the other direction from very slightly above 6000 to 10,000 cycles. By proper terminal arrangements this will provide on a single pair of wires the equivalent of ten full-duplex telegraph channels. From what has been said, it will appear that there is left still available a substantial frequency range which may, if desired, be used to provide either other telegraph channels, or, if the needs of the service require them, additional telephone channels.

Frequency Assignments. From the statements regarding filters and the methods of obtaining two-way operation, it will be evident that it is possible to select the frequencies for the various telephone and telegraph channels in a variety of ways. What assignment of frequencies to the various channels is best suited to a particular installation depends upon the engineering and economic considerations involved. For example, where there is only a single pair of wires available and it is desired to secure over this pair as many carrier telephone channels as possible, it may be economical to go to considerable expense in securing sufficient uniformity in the line so that its impedance can be readily balanced by the artificial line networks, thereby making it possible to use the same range of frequency for securing a two-way telephone channel. The harmonic frequency arrangement already described is particularly useful in such a case.

If, however, it is desired to operate carrier systems over a number of pairs of wires on the same lead, considerations of cross-talk, which will be explained more fully later in a section dealing with lines, make it highly desirable that different frequencies be used for operation in the two directions. Under this condition it is not necessary to secure the uniformity of line impedance which is required when the same frequency is employed in both directions. Of the possible frequency assignments for the oppositely directed channels, one which has proved very convenient is that in which all of the channels in one direction employ carrier frequencies below a certain value, and all the channels in the opposite direction carrier frequencies above this value. This grouped arrangement simplifies the selective circuits both at the repeater points and at the terminals; for the separation between oppositely directed currents which is accomplished by the balancing of the high-frequency line when the

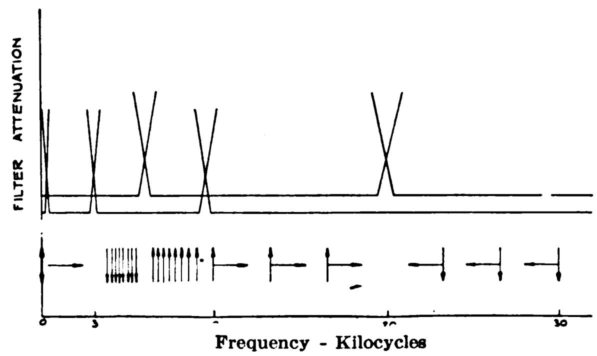

FIG. 25

same frequencies are used in both directions can, with this grouped arrangement, be accomplished by a combination of high- and low-pass filters of the type shown in Fig. 15. Fig. 24 shows schematically a carrier telephone system employing filters of this sort both at the terminals and at an intermediate repeater station.

A very workable assignment of frequencies to telephone and telegraph on the same pair is shown in Fig. 25. The arrows at the lower part of the figure indicate the positions assigned in the frequency scale to the different types of transmission. Beginning at zero frequency there is assigned to the direct-

current telegraph a narrow band. The range extending from 200 to 2000 cycles and represented by the horizontal arrow is the frequency band of ordinary telephony. In the interval between 3333 and 6000 cycles is a group of eight one-way carrier telegraph channels indicated by vertical arrows. In the interval between 6000 and 10,000 are the eight oppositely directed channels, which with those of lower frequency may

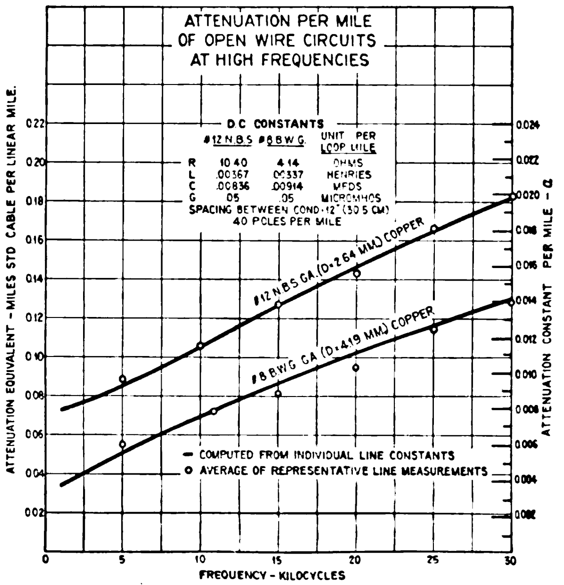

Fig. 26

constitute eight full duplex telegraph circuits. The frequency range above 10,000 is assigned to three two-way carrier telephone channels. These are each designated by a vertical arrow indicating the position of the carrier frequency and the direction of transmission, and a horizontal arrow indicating the position of the side band with respect to the carrier frequency.

Above there are given, one above the other, the idealized attenuation characteristics of a pair of separating filters for use with this assignment of frequencies. The lower of the two is so designed that each filter transmits only those frequencies which are assigned to one particular purpose. Such filters would be used for separating into individual circuits the currents used for carrier telephony, carrier telegraphy, ordinary telephony and ordinary telegraphy and thus facilitating their distribution in the central offices. The filters shown above are used, as is illustrated in Fig. 23, for separating in the carrier current circuits the currents transmitted in opposite directions.

Lines

General. The electrical design of carrier systems is determined in large part by the problems which arise in the transmission of the carrier currents over the line wires. The comparatively high frequencies used in carrier transmission attenuate much more rapidly in passing along the lines, and have a much greater tendency to cause interference in adjacent circuits than do the ordinary telephone frequencies. Both attenuation and interference increase rapidly with increase in frequency. Because of this it has been found most economical to make use of the frequency range commencing immediately above the voice range. The systems which have so far been put into commercial use employ frequencies up to about 30,000 cycles.

Because of the high attenuation and interference, carrier transmission is particularly dependent on the use in the circuit of repeaters placed at comparatively frequent intervals. To indicate the importance of repeaters, it is interesting to note that if the Harrisburg-Chicago carrier telephone system, which spans about 750 miles, as described below, were operated without repeaters, it would be necessary under the most favorable line conditions to apply at the sending end of the highest-frequency channel a power of 60 kilowatts. By the use of intermediate repeaters the high-frequency power at no point exceeds 0.1 watt.

Some of the experimenters in this art have had the misconception that the mode of transmission of the high frequencies employed in carrier operation was different from that of the ordinary telephone frequencies, and that the carrier frequencies had some unexplained property whereby, although guided by the line wires, large energy losses in the line wires were avoided. There is, however, no theoretical or experimental basis for this idea. As a matter of fact, the line attenuation of carrier currents is considerably

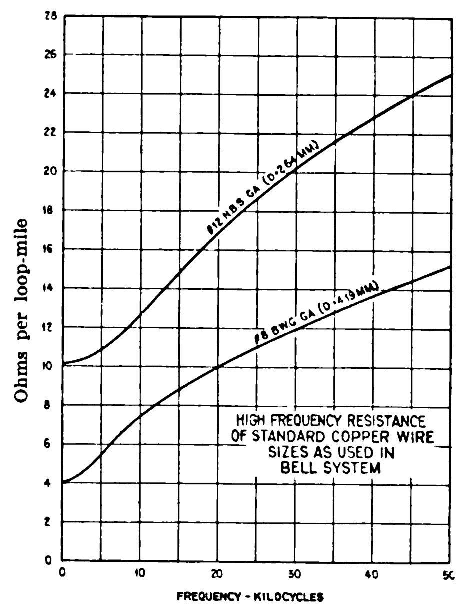

Fig. 27

greater than for telephone frequencies and increases rapidly with frequency, due to the increased resistance of the line wires, and increased effective leakage between the line wires at the carrier frequencies. While it is, of course, proper to picture the mechanism of carrier transmission as one in which the energy is contained in the electromagnetic waves, which are guided by the line wires, this is no less true for the transmission of low frequencies. The difference between

radio and wire transmission, whether of high or low frequency, is the difference between unguided and guided waves.

Open Wire Characteristics at Carrier Frequencies. The two sizes of wire in most common use for open-wire telephone lines in this country are No. 12 N. B. S. gage (0.104 in. diameter) and No. 8 B. W. G. (0.165 in. diameter). These wires are strung on pole lines with a normal separation of twelve inches between their centers.

The curves of Fig. 26 give the values of the attenuation constant[22] at different frequencies for circuits of these sizes of wire. The attenuation follows the usual line formulas. That is, the ratio of the currents

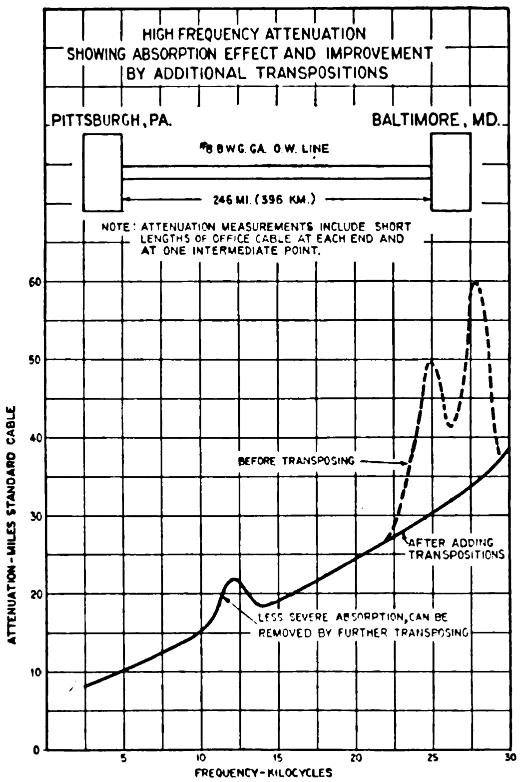

FIG. 28

i_1 and i_2 at two points on a transmission line separated by a distance l, assuming the line so terminated as to make reflection effects negligible, is

$$\frac{i_2}{i_1} = e^{-l\alpha}$$

in which α is the real part of the expression

$$\sqrt{(R + j\,p\,L)\,(G + j\,p\,C)}$$

In this expression R and L are the effective loop series resistance and inductance per unit length and G and C are the effective conductance and capacitance between the wires, per unit length.

22. NOTE: A convenient practical unit of attenuation which has gained large use in telephone engineering is that of the "mile of standard cable," in which α at 800 cycles equals 0.109. The attenuation at carrier frequencies is expressed in terms of the miles of standard cable which at 800 cycles has the same attenuation.

The formulas covering the action of transmission lines to alternating currents are so well understood[23] that the discussion here will be limited to certain

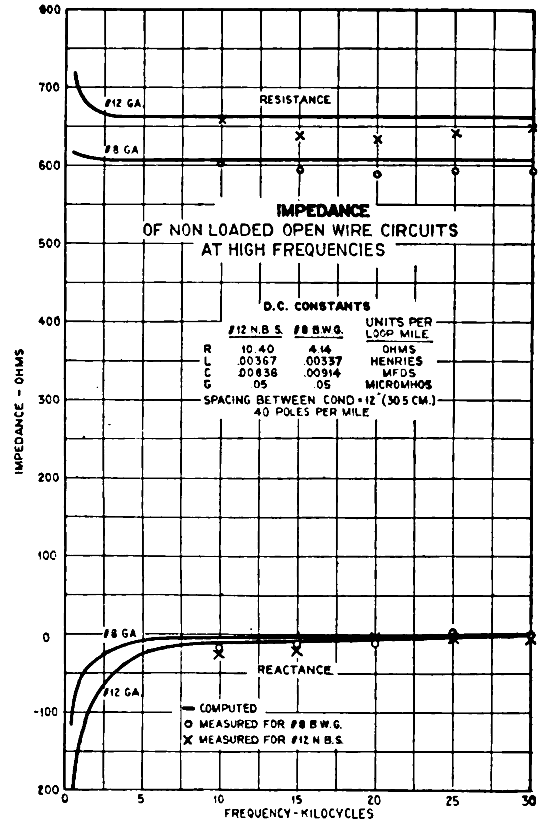

FIG. 29

features of particular interest in connection with carrier systems.

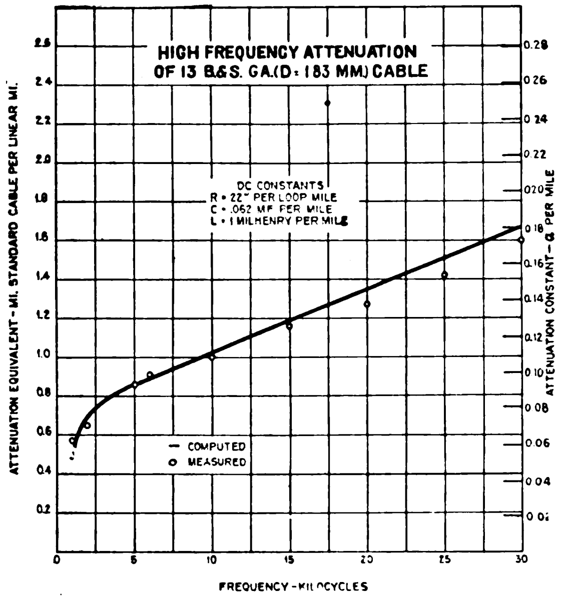

FIG. 30

23. J. A. Fleming: "The Propagation of Electric Currents in Telephone and Telegraph Conductors."

A. E. Kennelly: "The Application of Hyperbolic Functions to Electrical Engineering Problems."

John Mills: "Radio Communication, Theory and Methods, with an Appendix on Transmission over Wires."

It is found that the constants L and C are practically the same at high as at low frequencies. R may be computed by the usual "skin effect" formulas. Its rapid increase in value with increase in frequency is shown in Fig. 27.

The determination of G represents a more difficult task since no theoretical relation has been established

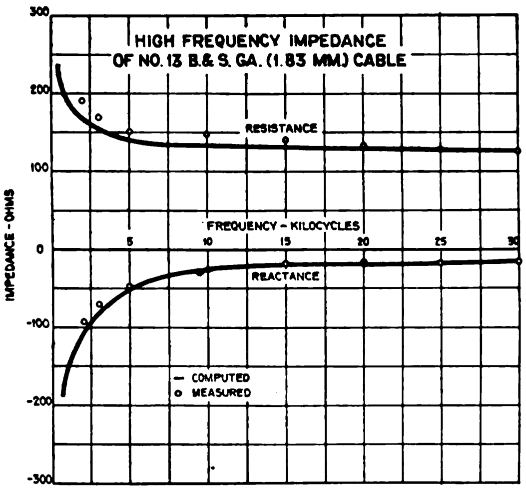

Fig. 31

between the effective conductance between the wires and frequency. In computing the curve shown, the value of G was taken from measurements of the effective insulation of a group of glass line insulators exposed to ordinary weather conditions, and assumes therefore that the effective leakage occurs only at the insulators. The conductance, for example, at 25 kilocyles, under

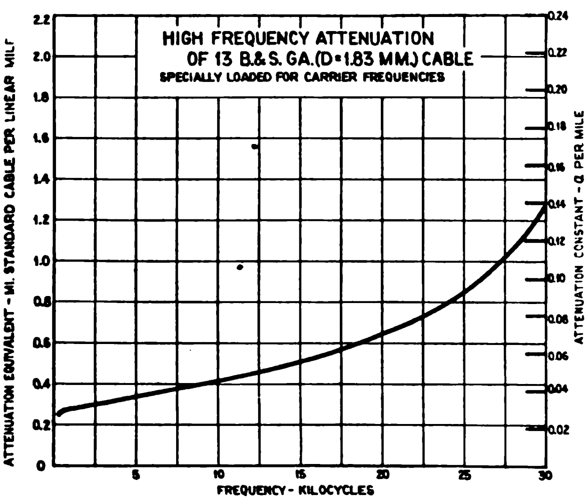

Fig. 32

normal dry weather conditions, is found to be roughly 200 times that measured with direct current. It will be noted that the curves computed with the values of the constants so obtained are checked very closely by the actual field measurements which are indicated on the curves by small circles. Since the leakage plays a large part in determining the attenuation, substantial changes in attenuation occur for varying weather conditions. Under wet weather conditions the attenuation will rise materially higher than that shown in the above curve.

The apparent attenuation of a circuit may be largely increased by the setting up of induced currents in adjacent wires carried on the same pole line. This is illustrated in the curve of Fig. 28, which is for one of the circuits employed in the operation of the first commercial carrier telephone system between Baltimore and Pittsburgh. The dotted curve represents excess attenuation originally found in the circuit due to such absorption. After additional transpositions had been cut into the circuit it finally gave the attenuation shown

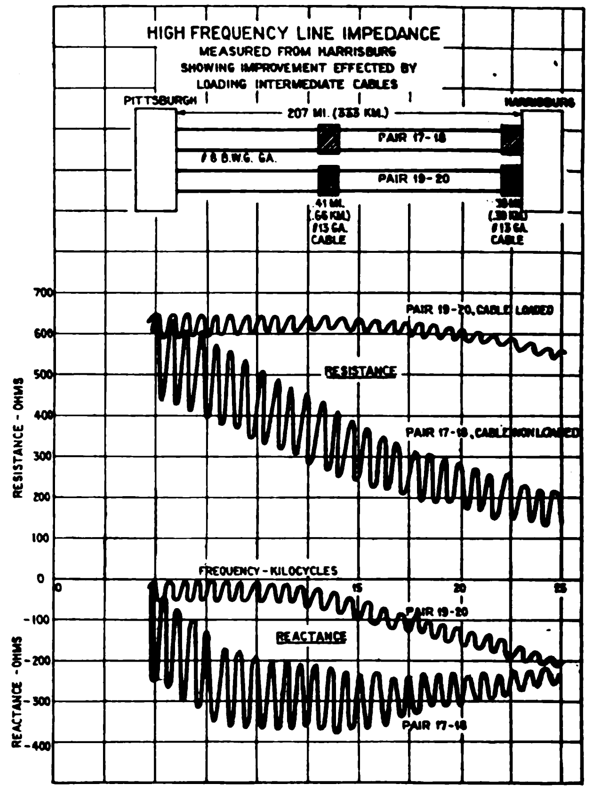

Fig. 33

in the full line curve. The smaller attenuation hump shown in the curve at about 12,000 cycles was not eliminated, as its effect was not considered sufficiently serious to justify the expense of further transpositions.

The impedance of a circuit as viewed at terminal and intermediate repeater points is important in determining the proportioning of the connecting apparatus and in determining the amount of amplification which can be given, in systems depending on balance. Fig. 29 shows the impedance characteristic of a long No. 8 B. W. G. circuit. The curves follow the usual line formulas for characteristic impedance. It will be noted that the impedance is practically a pure resistance with a value of approximately 600 ohms. The fact that the reactance component is negligible makes it possible to design the selecting circuits regardless of the particular line over which a system is to operate.

The effect on repeater amplification of irregularities in impedance is covered in the section under "Line Balancing" below.

Cable. Transmission over cables will be discussed here in connection with the unavoidable use of short lengths of cable in open wire lines, for toll entrance in bringing the circuits into the central offices, at river crossings, in passing through cities, etc. Such lengths of cable have two effects:

a. They introduce a considerable transmission loss due to the inefficiency of cable circuits at these higher frequencies, and

b. They introduce a large irregularity in impedance characteristics which, in systems depending on balance for duplex operation, affects radically the amount of amplification which may be obtained at repeater points.

Fig. 30 shows the attenuation, and Fig. 31 shows the

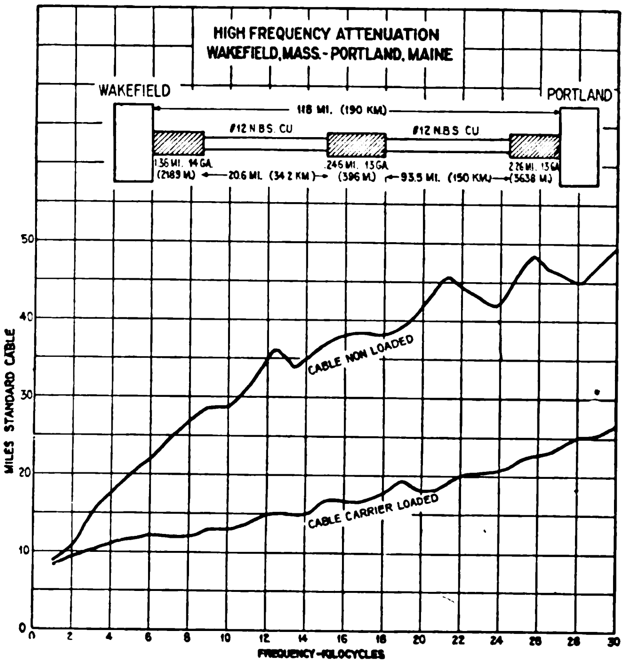

Fig. 34

impedance of a No. 13 B. & S. gage paper-insulated cable circuit of the ordinary telephone type.

To reduce both the attenuation of the circuits at these frequencies and the impedance irregularity which short lengths of cable introduce, there has been developed a system of coil inductance loading.

Loading for Carrier Frequencies. The loading systems which have been developed for cable are adapted to transmit frequencies up to about 30,000 cycles. The coils are spaced about 1000 feet apart, and the amount of inductance is chosen so as to give the cable circuits the same characteristic impedance as the lines to which they are connected. Fig. 32 shows the attenuation of a No. 13 gage cable so loaded.

Fig. 33 shows the impedance of a section of line between Harrisburg and Pittsburg as measured at Harrisburg, including two lengths of cable as indicated in the figure. It will be noted that the impedance when the cables are non-loaded is very irregular. The rapid variations in impedance are caused by reflections from the intermediate length of cable at Altoona, whereas the general drop of the complete impedance curve is due to the terminal cable at Harrisburg. It will be noted in this case that due to the terminal cable the reactance of the circuit as measured from the terminal is not negligible. The decrease in irregularity in impedance as the frequency increases is due to the fact that the attenuation increases with frequency, so that the cable at Altoona is electrically farther away at the higher frequencies. Since, however, the large attenuation has to be made up by larger repeater gains, the smaller apparent irregularity at the higher frequencies is of equal or greater practical importance than that at low frequencies. It will be noted furthermore that the loading largely overcomes the effect of the two lengths of cable. The slight remaining reactance component, which occurs at the higher frequencies, is largely due to the office wiring at the end where the measurements were made; and the slight remaining irregularity is due to some office wiring at Altoona.

Fig. 34 illustrates the effect on attenuation of the loading of intermediate lengths of cable. It shows the improvement introduced in the attenuation of a circuit between Wakefield, Mass., and Portland, Me., due to the loading of three lengths of intermediate cable. This section is a part of the circuit of a carrier telephone installation between Boston, Mass., and Bangor, Me. The importance of loading will be appreciated in this case by noting that at 25 kilocycles the received energy is increased about two hundred times by the loading of the cables.

Under some conditions it has been found convenient to leave lengths of cable in carrier systems unloaded, and to install auto-transformers between the cable and the open-wire circuits to reduce the reflection losses introduced by the cables.

Line Balancing for Two-Way Operation. As already pointed out, two-way operation may be carried out either by the use of different frequencies in the two directions, or by using the same frequency for the two directions but using duplex balancing arrangements at the terminals. When different frequencies are used in the two directions it is sometimes convenient to employ line balance to supplement the selective circuits.

The general problem of line balancing was discussed in some detail in the paper on telephone repeaters already referred to.[24] It will be noted by referring again to the impedance characteristic of a long uniform length of open wire circuit (Fig. 29) that a balance can be obtained by employing an artificial line consisting simply of a non-inductive resistance of about 600 ohms. Moreover, this resistance gives a good balance for all of the channels employed in a carrier system.

24. Gherardi-Jewett, loc. cit.

For systems requiring it, balance must be obtained not only at intermediate repeater points but also at each terminal, since the terminal set is itself inherently a repeater. Fig. 35 shows diagrammatically a typical balancing arrangement in which the open-wire and connected apparatus on one side of the hybrid coil is balanced by a resistance and connected apparatus on the opposite side. The office wiring is balanced by a condenser and the high-pass and low-pass filters in the line are balanced by similar arrangements in the balancing line.

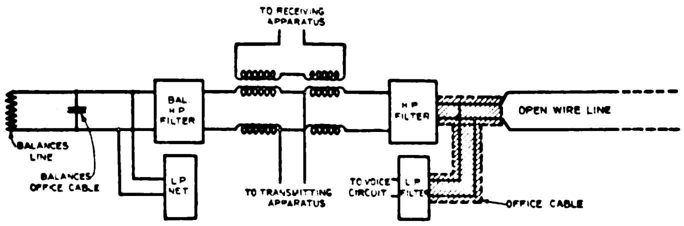

FIG. 35

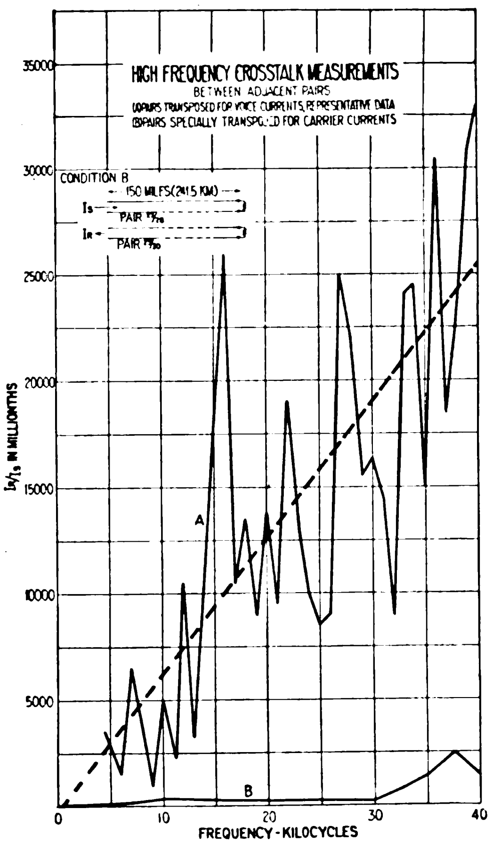

FIG. 36

There has already been pointed out in the section above the manner in which irregularities due to intermediate lengths of cable are cared for by loading. It is important that lines used for carrier operation shall be kept as free as possible from intermediate lengths of cable, lengths of twisted pair, etc. It will be noted that the irregularities in impedance so introduced are similar to those which occur at ordinary telephone frequencies, and were discussed in some detail in the paper on telephone repeaters.

Interference between Circuits—Transpositions. Any general use of carrier systems in the telephone plant requires that it be possible to operate a number of similar systems over the same pole line without mutual interference, that is, to transmit the same range of carrier frequencies over a number of circuits running closely together on the same line, with only negligible interference between channels of different carrier systems.

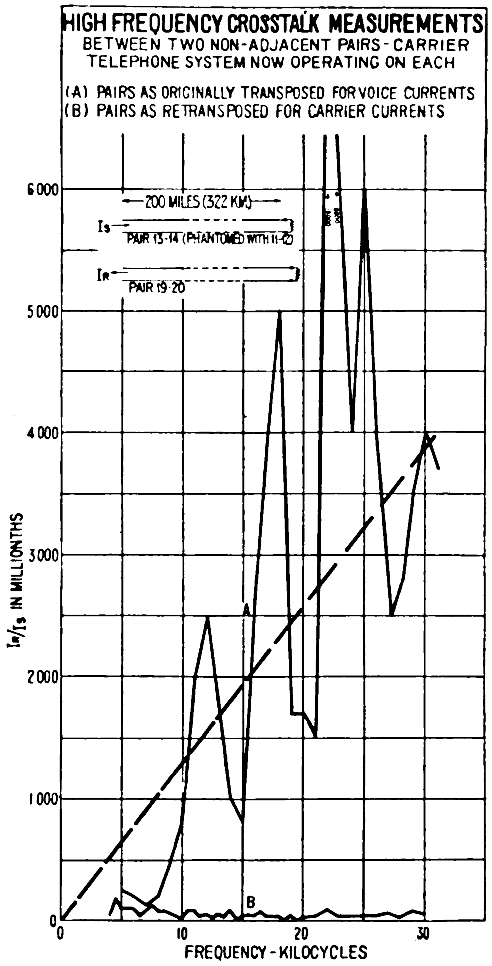

FIG. 37

Inasmuch as the only means available for preventing interference between circuits where the same carrier frequency is employed in both directions is that of balance between circuits, effected by transpositions, it is obvious that where a number of carrier systems are to be operated on the same pole line, the circuits must be operated on the metallic and not on the ground return basis. Metallic circuits are also desirable for reducing foreign high-frequency interference, such as "static" and that from high-power radio stations employing frequencies in the carrier range.

The transpositions existing in open-wire telephone circuits are generally inadequate to balance the cir-

cuits sufficiently accurately for the higher frequencies of carrier transmission.

Fig. 36 shows the values of interference at different frequencies between two pairs of wires which are adjacent on the crossarm. Curve *A* shows typical values for circuits as measured with the ordinary telephone transpositions in them. Curve *B* indicates the great reduction made in the cross-talk by inserting transpositions in both of two circuits extending between Toledo, Ohio and South Bend, Indiana, making the average number per circuit about six per mile. Inasmuch as these circuits are adjacent pairs on the line, the exposure between them is the maximum possible.

In Fig. 37, Curves *A* and *B* show, in the same manner, the cross-talk between two circuits with the ordinary transpositions and after special transpositions had been cut into them. Here the circuits are not immediately adjacent but are separated on the crossarm by two other pairs of wires. The two pairs covered by this figure extend between Harrisburg and Pittsburgh, and are in commercial use for carrier systems.

As a result of a considerable amount of line measurements of the above types with different transposition systems, and from theoretical investigation of cross-talk at these frequencies, it has been determined that the interference limitations are roughly as follows:

Where carrier systems employ the same frequencies for transmission in the two directions, it would not be practicable to operate systems on all the pairs of a line, since the number of transpositions required would be prohibitively large. In fact, in a lead carrying a considerable number of circuits, the transpositions would have to be more closely spaced than are the poles under present standard construction. It is possible, however, to reduce greatly the effect of interference between circuits, by employing systems using different frequencies in the two directions, and arranging so that all of the systems employ the same range of frequencies in each direction. This reduces, of course, the number of two-way channels which may be obtained per pair. It is not certain, however, that even with this arrangement of carrier systems it would be economical to apply carrier to all pairs of a pole line.

Much has already been accomplished, however, in transposing a limited number of pairs on a pole line for carrier operation, and this constitutes the practical problem in most of the present cases; for example, two carrier telephone systems and one carrier telegraph system are operating over the same pole line in the section of the New York-Chicago line between Harrisburg and Pittsburgh, a distance of about 200 miles. While the circuits involved in this case are not adjacent on the crossarm, the systems employ the same frequencies for transmission in opposite directions and therefore represent a severe condition as regards interference.

Noise Interference. As the frequencies used in carrier systems are considerably higher than the harmonics which are generally present in power systems, these circuits are less subject to noise from power interference than are the ordinary telephone

Fig. 38

circuits. They are not free from such interference, however, since high frequencies may be set up in power systems by the charging of lightning protectors, switching, etc. Since the circuits cannot in general be as well balanced to ground at carrier frequencies as at ordinary telephone frequencies, the carrier channels have shown a certain amount of interference from atmospheric electrical effects—that is, so-called

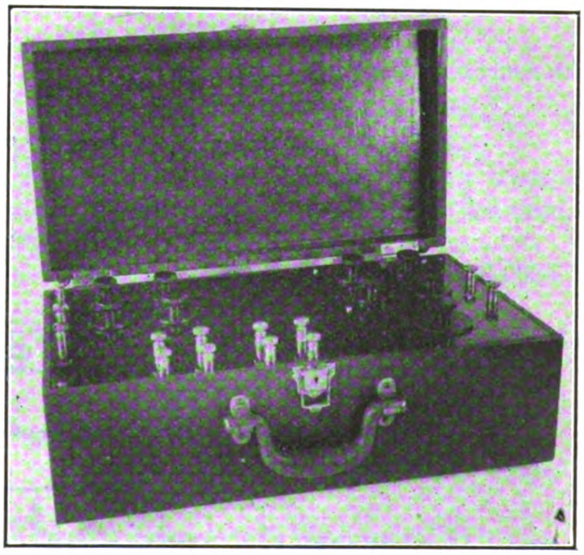

Fig. 39

static. Some interference has also been experienced from high-power long-distance radio systems which are now employing frequencies within the same range.

Line-Measuring Apparatus. To put the lines in proper shape for carrier operation and to maintain

them properly has necessitated the development of a suitable measuring technique and of portable measuring units, including a high-frequency oscillator, high-frequency impedance bridge, detector circuits, thermocouples, etc.

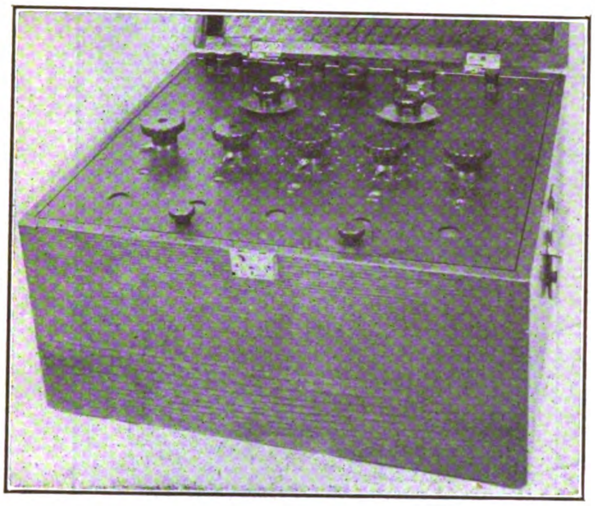

Fig. 40

A photograph of a portable high-frequency oscillator designed for testing work is shown in Fig. 38. This involves the use of four vacuum tubes and affords stable outputs as high as 50 milliamperes into an average line impedance. Its frequency range extends from 100 cycles to 50 kilocycles, and it is designed to operate on telephone-office power-supply sources.

Fig. 39 shows a high-frequency bridge of the differential-transformer type with a normal operating range covering that of the oscillator above mentioned, and capable of an accuracy throughout this range of one-quarter of one per cent.

Fig. 40 shows a high-frequency detector unit for

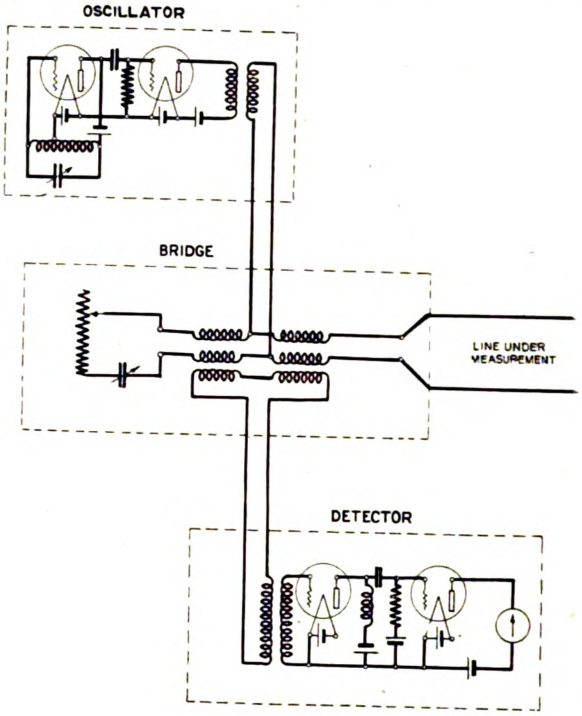

Fig. 41

use in bridge measurements. This involves the use of several vacuum tubes in an amplifier-detector circuit with an optional detecting arrangement allowing either:

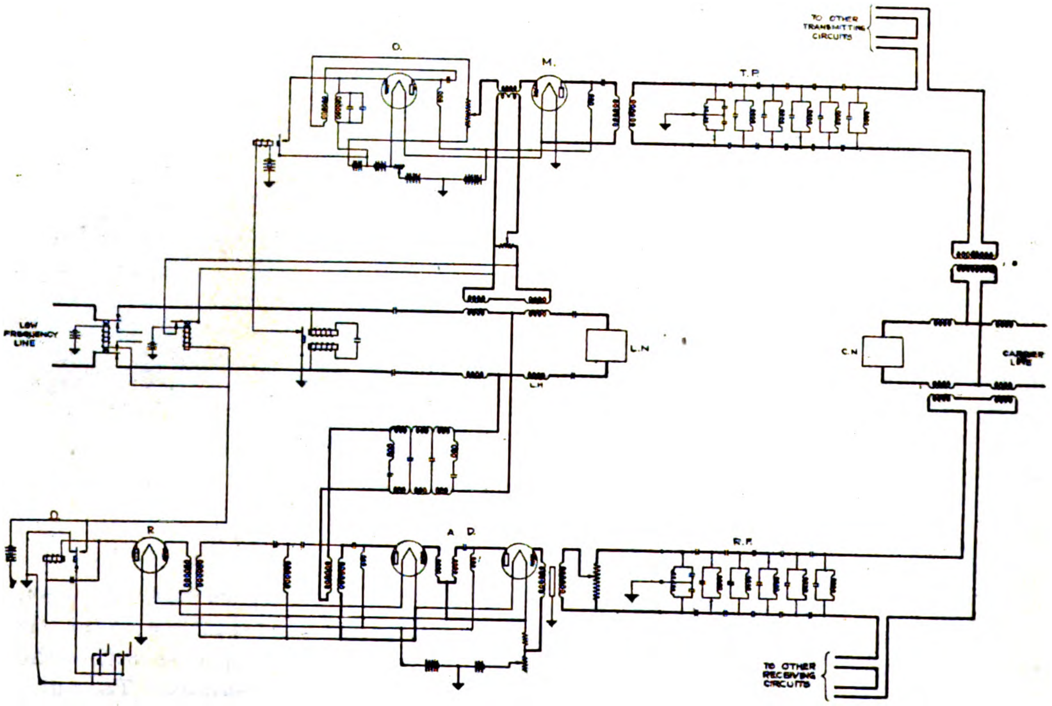

Fig. 42

a. Recording on a direct-current galvanometer, or
b. The use of a telephone receiver.

Attenuation measurements have been carried out largely by the use of thermocouple meter circuits in conjunction with an oscillator of the general type above mentioned. This permits measuring directly the attenuations of lines up to about 250 miles in length. The current sent into the line is compared with the corresponding received current, with the circuit properly terminated. An over-all accuracy of about 1 per cent is usually obtained. Currents as low as 0.25 milliampere may be read with this method thus making it possible to measure attenuations involving current ratios up to 1:200, or a line length equivalent to approximately 50 miles of standard cable. For greater lengths of line, circuits involving the use of the sensitive detector circuit above mentioned have been employed using comparison methods.

Impedance measurements are made with the oscillator, bridge and detector circuits above noted. A schematic circuit arrangement is shown on Fig. 41.

(To be continued)

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p. 517

Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils

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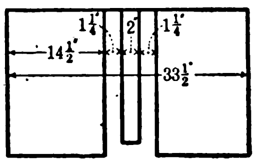
Research Engineer, Westinghouse Elec. & Mfg. Co.

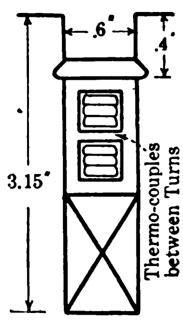
(Concluded from page 340 of JOURNAL for April 1921.)

Calculations by Equations and Test Results

In order to check the equations derived, thermocouples were placed in the armature (stator) coils of a 2400-volts, three-phase, 60-cycle, 3600-rev. per min., turbo generator. The following are the proportions of the generator:



Length of core $33\frac{1}{2}$ inches.
Number of slots 48.
Size of slot 0.6 in $\times$ 3.15 in.
Number of conductors per slot $= 4$ ($N = 2$).
Size of conductor = three 0.144 in. by 0.325 in.
Connection one circuit star.
Throw of coils, slot 1 to slot 13.
Approx. length of ¼ mean turn = 32.5 in.



Currents in upper coils in which thermocouples were embedded were out of phase by 120 electrical degrees with currents in coils in bottom of slot.

The ends of the coils were separated from one another between layers as well as circumferentially. The cooling surface was therefore taken as the perimeter of the coil (per inch longitudinally).

Thermocouples were also placed in the iron, about half-way down the tooth. The temperatures rises in the iron are shown in Fig. 7 for distribution of temperatures axially.

It will be seen that the temperature distribution in the iron is nearly that of a parabola, if the origin for x be taken as the end of the radial duct near the vertical center line, thus making L_e 14 ½ inches.

Embedded Portion

D_a = Insulation thickness $= \dfrac{0.6 \text{ in.} - 0.325 \text{ in.}}{2} =$ 0.138 in.

Gaged size of outside of coil = 0.549 in. by 1.197 in.

Outside surface of two sides plus width = 1.197 in. $\times$ 2 + 0.549 in. = 2.943 in.

Bare Copper surface = 0.144 in. $\times$ 12 + 0.325 in = 2.05 in.

Q_e = Average of above = 2.5 sq. in. (one inch axially)

ϵ_e = Eddy factor for upper coil = 1.092.[10]

ϵ_e = Eddy factor for lower coil = 1.065.

To avoid figuring twice, with so small difference in loss the eddy factor has been taken as 1.08 = ϵ_a.

k_e = thermal conductivity taken as 0.0025 watts per sq. in. per in. per deg. cent.[11]

L_e = length of embedded portion considered = 14.5 in.

End Windings

Gage size of ends = 0.57 in. by 1.28 in.

Q' = external surface = 2 (0.57 in. + 1.28 in.) = 37. sq. in.

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10. Figured by formula in paper by R. E. Gilman, "Eddy Current Losses in Armature Conductors." A. I. E. E. June, 1920.

11. Data on transverse thermal conductivity of coil wrappers consisting of cement paper and mica are given in article by T. S. Taylor in *Electrical World* for Feb. 14, 1920 as about 0.00245 for 6600 volts. Any figure must be regarded as approximate. The low values are largely due to contact resistance between layers of insulation.

Internal surfaces = 0.144 in. × 12 + 0.325 in. × 2 = 2.48 sq. in.

Q_b = average of 3.7 and 2.48 = 3.1 sq. in.

D_b = insulation thickness = $\dfrac{0.57 \text{ in.} - 0.325 \text{ in.}}{2}$ = 0.122 in.

ϵ_b = eddy current factor for ends = 1.03

k_b = thermal conductivity of ends taken as 0.0035 watts, per inch per sq. in. per deg. cent.[12]

k' = emissivity from coil-end surfaces taken as 0.045 watts, per sq. in. per deg. cent.[13]

L_b = length from end of core to end of winding = 15.75 in.

General Data

k_c = thermal conductivity of copper taken as 9 watts per sq. in. per in. per deg. cent.

q = cross-section of conductor = 0.138 sq. in.

θ_0 = air temperature around coil ends in test = 30.7 deg. cent.

Average ingoing air temperature = 23.7 deg. cent.

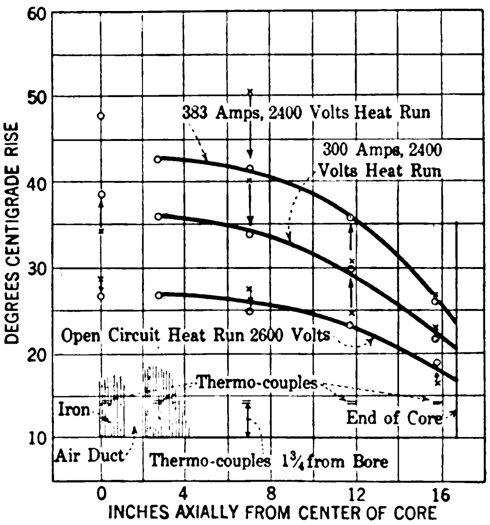

FIG. 7—CURVES SHOWING VARIATION OF TEMPERATURE RISES OF IRON (AXIALLY)

Heat Run at 300 *Ampere,* 2400 *Volts*

$$I^2 r = \frac{\rho N I^2}{q} = \frac{0.625 \times 2 \times 300^2}{10^6 \times 0.138} = 0.818 \text{ watt.}$$

$$K_a = \frac{k_a Q_a}{D_a} = \frac{0.0025 \times 2.5}{0.138} = 0.0453.$$

$$K_b = \frac{k_b Q_b}{D_b} = \frac{0.0035 \times 3.1}{0.122} = 0.089.$$

12. From unpublished data on transverse thermal conductivity of varnished cambric and linen tape used on ends.

13. From unpublished data. See some data and description of tests, by T. S. Taylor in A. S. M. E. *Journal*, April 1920.

$$\gamma = \frac{1}{1 + \dfrac{0.089}{0.045 \times 3.7}} = 0.652 \text{ (equation (\textbf{16})}.$$

From Fig. 7, $\theta_m = 36.3 + 23.7 = 60°$ $(x = 0)$

From Fig. 7, $\theta_i = 20.5 + 23.7 = 44.2$ for $x = L_a = 14.5$ in.

Assuming parabolic distribution of tooth temperatures, from equation (**53**),

$$f = \frac{x^2}{1 - \dfrac{\theta_i}{\theta_m}} = \frac{\overline{14.5}^2}{1 - \dfrac{44.2}{60}} = 800$$

This value for f gives very close agreement between the iron temperature curve figured from equation (**53**) and test.

$$\theta_i = 60\left(1 - \frac{x^2}{800}\right)$$

Calculations for Constant Iron Temperature

Figuring on basis of constant iron temperature, the average iron temperature is:

$$\frac{1}{14.5}\int_{x=0}^{x=14.5} \theta_i \, d x = \frac{1}{14.5}\int_0^{14.5} 60\left(1 - \frac{x^2}{800}\right) d x = 54.75 \text{ deg.}$$

$$\theta_{a0} = \frac{B_a}{A_a} = \frac{0.0453 \times 54.75 - 1.08 \times .818}{0.0453 - 1.08 \times 0.818 \times 0.00427}$$

$$= \frac{3.364}{0.04152} = 81 \text{ deg. (Eq. \textbf{13})}.$$

$$A_a = \frac{0.04152}{9 \times 2 \times 0.138} = 0.06172; \sqrt{A_a} = 0.1292$$

(Eq. **7**)

$\sqrt{A_a}\, L_a = 0.1292 \times 14.5 = 1.876$

Tanh 1.876 = 0.953

Cosh 1.876 = 3.33

Values of the hyperbolic functions may be read from Fig. 8.

$$\theta_{b0} = \frac{B_b}{A_b}$$

$$= \frac{0.652 \times 0.089 \times 30.7 + 1.03 \times 0.818}{0.0652 \times 0.089 - 1.03 \times 0.818 \times 0.00427}$$

$$= \frac{2.63}{0.0545} = 48.3 \text{ deg.} \quad \text{(Eq. \textbf{27}.)}$$

$$A_b = \frac{0.0545}{9 \times 2 \times 0.138} = 0.02192; \sqrt{A_b} = 0.148$$

(Eq. **22**).

$\sqrt{A_b}\, L_b = 2.335$

Tanh 2.335 = 0.98

Cosh 2.335 = 5.2

$$\beta = \frac{0.148 \times 0.98}{0.1292 \times 0.953} = 1.178 \text{ (Eq. } \mathbf{28a}\text{)}.$$

$$\theta_L = \frac{81 + 48.3 \times 1.178}{1 + 1.178} = 63.4 \text{ degrees (Eq. } \mathbf{29}\text{)}$$

$$\theta_a = 81 - \left(\frac{81 - 63.4}{3.33}\right) \cosh (0.1292\, x)$$

$$= 81 - 5.29 \cosh \ (0.1292\, x) \text{ (Eq. } \mathbf{11}\text{)}.$$

$$\theta_{max} = 81 - 5.29 = 75.71 \text{ degrees, or 52 degrees rise.}$$

$$\theta_b = 48.3 + \left(\frac{63.4 - 48.3}{5.2}\right) \cosh (0.148\, y)$$

$$= 48.3 + 2.9 \cosh (0.148\, y) \text{ (Eq. } \mathbf{25}\text{)}.$$

$$\theta_{min} = 48.3 + 2.9 = 51.2 \text{ degrees or 27.5 degrees rise.}$$

The solid curves in Fig. 9, were figured from the above equations for θ_a and θ_b, allowing for the in-

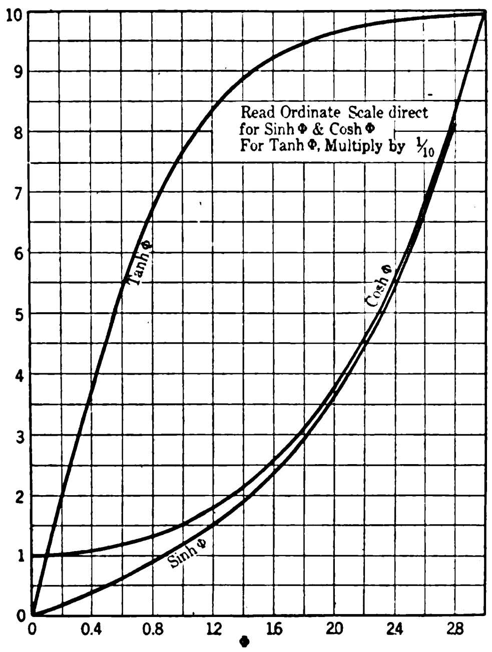

FIG. 8

going air temperature of 23.7 degrees. Using equation (33),

$$\theta_{av} = \frac{1}{30.25}\left[81 \times 14.5 + 48.3 \times 15.75 + \frac{81 - 48.3}{1 + 1.178}\left(\frac{0.98}{0.148} - \frac{1.178 \times 0.953}{0.1292}\right)\right]$$

$$= 62.9 \text{ deg., or 39.2 deg. rise.}$$

The 39.2 deg. average rise applied to 30.25 in. of coil length, which is 2.25 in. less than the quarter length of the mean turn, since the zero point of reference was taken at the end of iron adjacent to the radial vent duct near the vertical center line. If the temperature for those 2.25 in. be taken to be the same as the maximum (θ_{max} calculated = 52 deg. rise), the average temperature should be,

$$\frac{39.2 \text{ deg.} \times 30.25 \text{ in.} + 52 \text{ deg.} \times 2.25 \text{ in.}}{32.5 \text{ in.}}$$

$$= 40.1 \text{ deg. rise.}$$

The temperature rise measured by resistance as soon as possible after shut down was 35.3 deg., the difference being due at least in part, to the cooling of the winding before the resistance could be measured.

The average temperature in the embedded portion by equation (**33a**) is 48.3 deg. rise. Allowing for the 2.25 in. at 52 deg. rise, this average rise becomes 48.8 deg. rise.

Calculations for Parabolic Variation in Iron Temperature

The constants are the same as for constant core temperature.

$k_c = 9$, $q = 0.138$, $N = 2$, $I^2 R = 0.818$, $D_a = 0.138$, $Q_a = 2.5$, $\epsilon_a = 1.08$, $k_a = 0.0025$, $L_a = 14.5$, $K_a = 0.0453$, $D_b = 0.122$, $Q_b = 3.1$, $\epsilon_b = 1.03$, $k_b = 0.0035$, $L_b = 15.75$, $K_b = 0.089$, $Q' = 3.7$, $k' = 0.045$, $\gamma = 0.652$, $f = 800$, $\theta_m = 60$, $\theta_0 = 30.7$. $A_a = 0.01672$, $\sqrt{A_a} = 0.1292$, $\sqrt{A_a}\, L_a = 1{,}876$, $\tanh 1.876 = 0.953$, $\cosh 1.876 = 3.33$, $A_b = 0.02192$, $\sqrt{A_b} = 0.148$, $\sqrt{A_b}\, L_b = 2.335$, $\tanh 2.335 = 0.98$, $\cosh 2.335 = 5.2$.

$$\text{Then } H = \frac{60 \times 0.0453}{800 \times 9 \times 2 \times 0.138} = 0.00136 \text{ (Eq. } \mathbf{57}\text{)}$$

$$\theta_{a0} = \frac{B_a}{A_a} = \frac{0.0453 \times 60 + 1.08 \times 0.818}{0.0453 - 1.08 \times 0.818 \times 0.00427}$$

$$= \frac{3.604}{.04152} = 86.7 \text{ deg. (or 63 deg. rise).}$$

For end windings, $\theta_{b0} = 48.3$, and $\beta = 1.178$ as previously.

$$\theta_L = \frac{1}{1 + 1.178}\left[86.7 + 1.178 \times 48.3 - \frac{0.00136}{0.1672}\left(\overline{14.5}^2 + \frac{2}{0.01672} - \frac{2 \times 14.5}{0.1292 \times 0.953}\right)\right]$$

$$= 62.6 \text{ deg. (Eq. } \mathbf{62}\text{) or 38.9 deg. rise.}$$

$$\theta_a = 86.7 - \frac{0.00136}{0.01672}\, x^2 - \frac{2 \times 0.00136}{(0.01672)^2} - \frac{1}{3.33}\left[86.7 - 62.6 + \frac{0.00136}{0.1672} \times \overline{14.5}^2 + \frac{2 \times 0.00136}{(0.01672)^2}\right] \cosh (0.1292\, x)$$

$$= 77 - 0.0813\, x^2 + 0.81 \cosh (0.1292\, x) \text{ (Eq. } \mathbf{60}\text{)}.$$

For $x = 0$, $\theta_{max} = 77.8$ or 54.1 deg. rise

$$\theta_b = 48.3 + \left(\frac{62.6 - 48.3}{5.2} \right) \cosh (0.148\, y)$$

$$= 48.3 + 2.76 \cosh (0.148\, y) \quad \text{(Eq. 52)}$$

For $y = 0$, $\theta_{min} = 51.1$ or 27.4 deg. rise.

The points calculated from the above for θ_a and θ_b will be found plotted in Fig. 9. As will be seen there is comparatively little difference between the curves for constant core temperature and for parabolic core temperature. In fact there is so little difference that

$$\theta_{max} = \frac{\dfrac{1}{0.00427} + 63.4}{\cos \left(2175 \times 14.5 \sqrt{\dfrac{1.08 \times 0.625 \times 0.00427}{10^6 \times 9}} \right)} - \frac{1}{0.00427} = 119 \text{ deg. or } 95.3 \text{ deg. rise.}$$

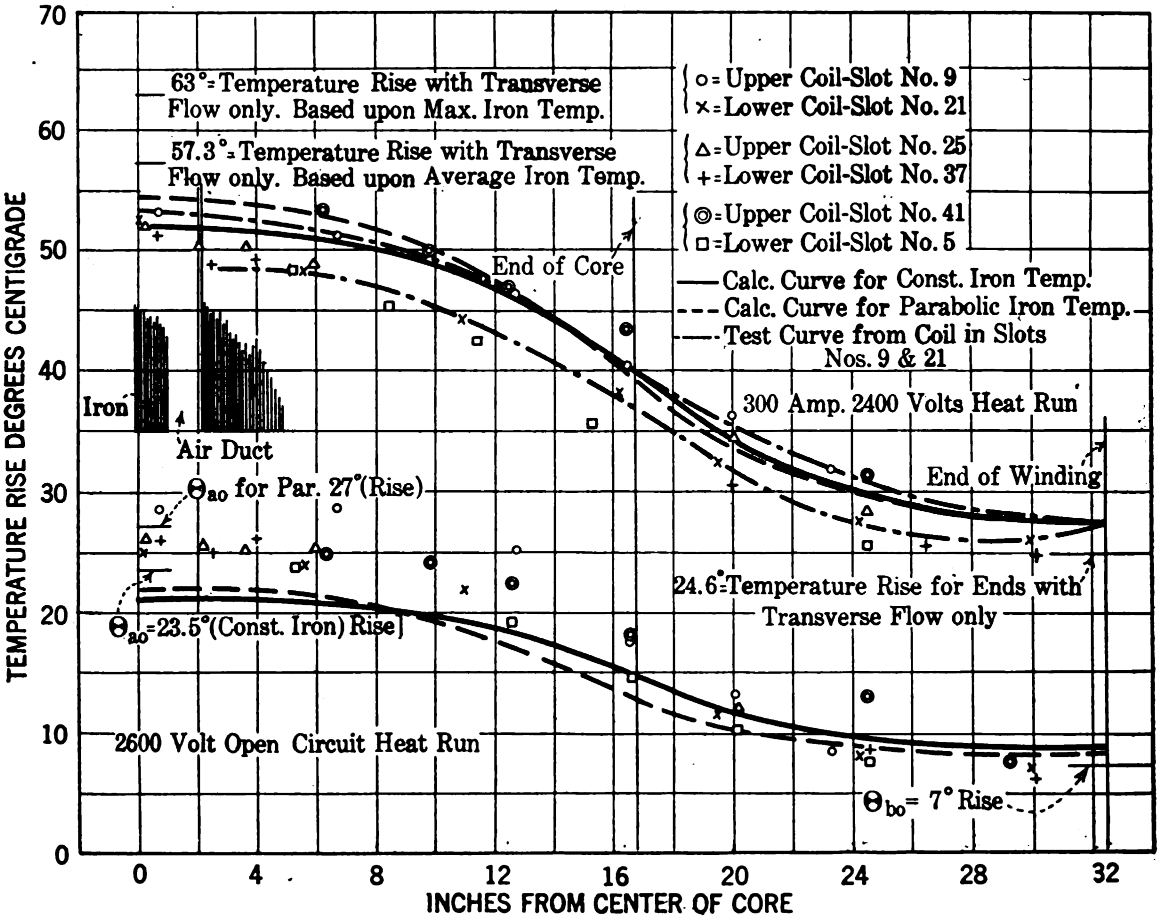

FIG. 9

it is questionable which is in closer agreement with the test points. In the calculations which follow, the constant core temperature figures are, n general, used.

Numerical Calculations Using Supplementary Equations

If equation (36) is employed, which assumes only longitudinal flow without allowing for the temperature coefficient, and if $\theta_L = 63.4$ deg., (as computed for constant core temperature, and if $\rho = \dfrac{0.825}{10^6}$ corresponding to 75 deg.,

$$\theta_{max} = 63.4 + \frac{1.08 \times 0.825 \times 2175^2 \times 14.5^2}{9 \times 2}$$

$$= 112.4 \text{ deg. total, or } 88.7 \text{ deg. rise.}$$

If equation (37) is used, which also assumes only longitudinal flow, but allows for the temperature coefficient,

Had k_c been taken as $(2.54 \times 3 =)$ 7.6 as in paper by Symonds and Walker, the temperature rise by same formula would have been 121 degrees; by Symonds and Walker's formula, the rise is 98.3 degrees. Or, using $k_c = 9$ in Symonds and Walker's formula, the rise is 87.3 degrees.

A comparison of these results is given in the following table:

TABLE I.

Maximum temperature rises by various means:

Longitudinal flow only				Transverse flow only		Combined flow		Test
Equa. No. 36	Equa. No. 37	Symond & Walker formula $k_c = 7.6$	Symond & Walker formula $k_c = 9$	Const. Core Temp.	Parabolic Core Temp.	Const. Core Temp.	Par. Core Temp.	
88.7	95.3	98.3	87.3	57.3	63	52	54.1	50.5 to 53.2

It should be noted that neglect of the transverse heat flow may lead to very considerable errors; even in a machine of medium core length the error introduced by considering only the longitudinal flow is very great, and in longer machines the error is even greater. Also, if the iron temperature be taken at its maximum value and the longitudinal flow be neglected, the calculated rise is 63 degrees; or there was an error, even in this machine of moderate length of core of about 11 degrees, or 21 per cent. If the longitudinal flow be neglected, and the average iron temperature be considered, the error in this particular machine or perhaps in longer machines is not very great. But it would be dangerous to draw any general conclusions, for as is pointed out in another part of this paper, under the subject of Eddy Currents, even in certain rather long machines, and certainly in short machines, the longitudinal flow has very material influence upon the maximum temperature. On the other hand, the close agreement of the maximum temperatures calculated either by means of the equation for constant core temperature or by the equation for parabolic core temperature with the test results shows the possibilities of estimating the maximum temperature by means of the equations derived in this paper.

The calculated temperature of the external surface of the end windings is given by equation (**38**), while the machine is in operation. Substituting in that equation,

$$\theta_e = \frac{0.089\ \theta_b + 0.045 \times 3.7 \times 30.7}{0.089 + 0.045 \times 3.7} = 0.349\ \theta_b + 20.2 \text{ deg.}$$

(The ingoing air temperature (23.7) deg.) must be deducted to secure rise).

Taking θ_b as the average of the two calculated curves in Fig. 9, (there are very slight differences), a comparison of calculated and test is given in Table II.

TABLE II

Distance along Copper from Center of Core	θ_b (Rise)	Calc. θ_e (Rise)	Test θ_e (Rise)
22.25	31.2	15.7	11.25
23.25	30.5	15.2	10.25
24	30	15.0	8.25

The test figure of 11.25 deg. is the average of three readings: 7.25, 9.75, and 16.75 deg. The lower temperatures by thermometer are probably largely due to the influence of the air striking the pad over the bulb of the thermometer, thereby lowering its reading. All engineers agree upon the inaccuracy of this method of judging temperatures.

The losses and the quantities of heat dissipated will now be accounted for. From equations **39a**, **40a** and **41a** calling $X = L_a$, and using figures for constant iron temperature.

$$(W_2)_a = \frac{9 \times 2 \times 0.138 \times 0.1292 \times 1.178\ (81-48.3) \times 0.953}{1 + 1.178} = 5.4 \text{ watts.}$$

$$(W_1)_a = 0.0453 \left[(81 - 54.75)\ 14.5 - \frac{(81 - 48.3)\ 1.178}{0.1292\ (1 + 1.178)} \times 0.953 \right] = 11.32 \text{ watts.}$$

$$(W)_a = 1.08 \times 0.818 \left[(1 + 0.00427 \times 81)\ 14.5 - \frac{0.00427\ (81 - 48.3)}{0.1292} \times \frac{1.178}{1 + 1.178} \times 0.953 \right] = 16.72 \text{ watts.}$$

Thus, in the embedded portion, the total watts generated (16.72) equal the watts dissipated by transverse flow (11.32) plus the watts flowing to the ends at $X = L_a$ (5.4). See eq. (**1**)).

Similarly, by substituting in equations **38b**, **40b** and **41b**.

$$(W_2)_b = 5.4 \text{ watts.}$$
$$(W_1)_b = 21.8 \text{ watts.}$$
$$(W)_b = 16.4 \text{ watts.}$$

Thus, the total watts dissipated from the end (21.8 watts) = the watts generated in the ends (16.4 watts) plus the watts received from the embedded portion (5.4 watts). (See eq. (**19**)). Note also the agreement between $(W_2)_a$ and $(W_2)_b$.

Another interesting check is that based on the total wattage. It was previously found that the average temperature for the 30.25 in. considered was 62.9 deg., so that the average watts per inch

= (1 + 0.00427 × 62.9) 0.818 = 1.039 exclusive of eddy loss. The average eddy factor is,

$$\frac{1.08 \times 14.5 \text{ in.} + 1.03 \times 15.75 \text{ in.}}{30.25 \text{ in.}} = 1.054.$$

Thus, the total loss for the 30.25 in.

$$= 1.039 \times 1.054 \times 30.25 = 33.15 \text{ watts.}$$

From the previous calculations, the loss

$$= 16.72 + 16.4 = 33.12 \text{ watts.}$$

The rate of generation of heat in the embedded portion is,

$$\frac{d\,w}{d\,x} = 1.08 \times 0.818\ (1 + 0.00427\ \theta_a)$$

For θ_a = 75.7 degrees (that is for $X = 0$),

$$\frac{d\,w}{d\,x} = 1.17 \text{ watts per inch.}$$

For $\theta_a = 63.4$ degrees ($X = L_a$),

$$\frac{d\,w}{d\,x} = 1.12 \text{ watts per inch.}$$

In the ends, $\dfrac{d\,w}{d\,y} = 1.07$ watts per inch for $y = L_b$.

In the ends, $\dfrac{d\,w}{d\,y} = 1.03$ watts per inch for $y = 0$.

The average rate of generation of heat in the embedded portion is

$$\frac{16.72 \text{ watts}}{14.5 \text{ in.}} = 1.15 \text{ watts per inch.}$$

$$\frac{d\,w_1}{d\,x} = K_a\ (\theta_a - \theta_i)$$

$= 0.95$ watts per inch for $X = 0$

$= 0.392$ watts per inch for $X = L_a$ (end of core).

The average $= \dfrac{11.32 \text{ watts}}{14.5 \text{ in.}} = 0.78$ watts per inch.

For the ends,

$$\left(\frac{d\,w_1}{d\,y}\right) = \gamma\, K_b\, (\theta_b - \theta_0)$$

$= 1.89$ watts per in. for $y = L_b$ (end of core).

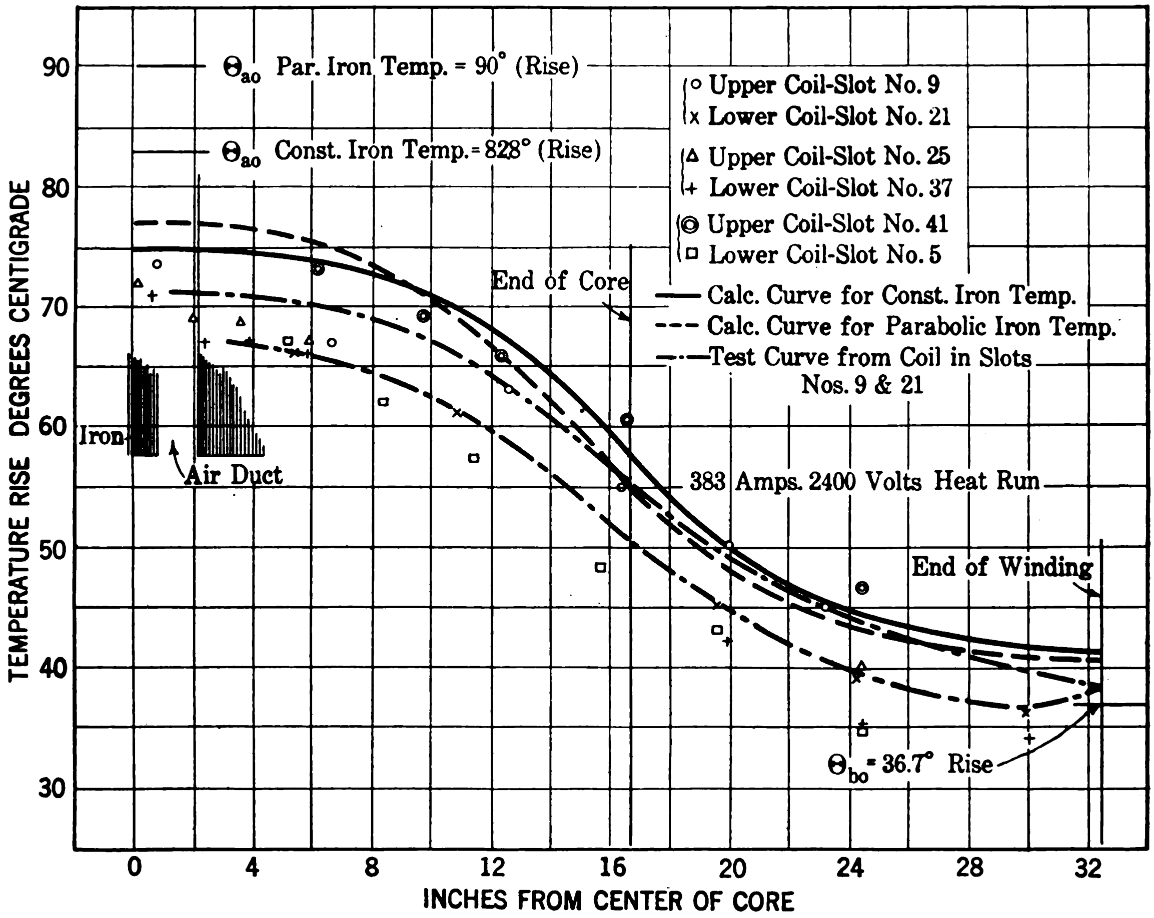

Fig. 10

The average for the ends is

$$\frac{16.4}{15.75} = 1.04 \text{ watts per inch.}$$

In accordance with the method of calculating eddy current loss, there is an abrupt change at the end of the core, and therefore the rate of generation of loss changes abruptly there also; that is, from 1.12 to 1.07 watts per inch. This abrupt change is more noticeable in machines with high-eddy current loss in the copper. The figures for watts per inch given above are the maxima and minima for the embedded and end portions.

The transverse rate of flow of heat in the embedded portion is,

$= 1.19$ watts per in. for $y = 0$ (end of winding).

The average $= \dfrac{21.8}{15.75} = 1.384$ watts per inch.

Thus, the maximum rate of transverse flow (and therefore of heat dissipation) is, in this particular case, about twice as great from the ends as from the embedded portion, and there is a very great change when passing from the embedded to the end winding portion.

The longitudinal flow is maximum at the end of the core (5.4 watts) and is zero for $X = 0$, and for $Y = 0$. Its relative values at any points can be determined from

the slope of the curve for temperature in Fig. 9, or may be obtained by substituting in equations (**39a**) and (**39b**).

Comments on Tests and Calculations

In addition to the tests made with 300-ampere load, and plotted in Fig. 9, tests were also made at no-load, open circuit at 2600 volts (Fig. 9), and with 383 amperes, 2400 volts, nearly zero power-factor, plotted in Fig. 10. The same constants, such as thermal conductivity, emissivity from the end windings, areas for transverse flow, etc., were used in the no-

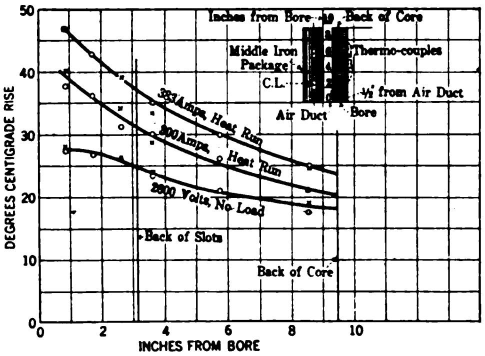

Fig. 11—Curves Showing Variation of Temperature Rises, Radially in the Iron

load and 383-amp. calculations as for the 300 ampere load calculations, with the exception that the eddy loss constant for the 383 amp. curves was taken slightly lower than for 300 amperes because the temperature was higher.

In Fig. 11 will be found some curves showing iron temperatures radially. They were measured 0.5 in. from one of the radial vent ducts. There is an unmistakable drop in temperature from the bore outward. The axial temperatures were measured 1¾ in. from the bore (Fig. 7), or a little more than half way down the tooth. The calculated curves in Figs. 9 and 10 were based upon the measured axial iron temperatures plotted in Fig. 7. The difference in tooth temperatures for the different depths undoubtedly explains much of the difference between the copper temperatures in the upper and lower coils. The constants used in the calculations were of such values as to give quite close agreement with the test curves for the upper coils. A comparison of Figs. 9 and 10 with Fig. 11 will show nearly the same difference in maximum temperature between the upper and lower coils as there was between the tooth temperatures for the corresponding regions.

One of the principal differences between test and calculation appears in the no-load curve (Fig 9). Evidently, with no I^2R and eddy current loss in the copper, some heat from the iron flows transversely from the iron to the copper, and is transmitted longitudinally to the coil-ends where it again flows transversely to the coil surfaces, and is taken up there by the air. In order for heat to flow from the iron to the copper, the copper must be at the lower temperature; this appears in the calculated curves. (See Figs. 7 and 9). On the other hand the test data plotted in Fig. 9 for the no load heat run, show maximum temperature rise of 28.5 deg. for the copper, whereas the maximum iron temperature (by curve) from Fig. 7 was 27.5 deg. rise. Since the large number of couples embedded in the iron necessitated the placing of them in various teeth, in all probability the iron temperatures used for calculating the curves in the no-load curve in Fig. 9 were lower than some of the iron temperatures adjacent to the coils. This statement is further proved by the fact that in Fig. 7 some of the test points were not on the curves as drawn.

The 383-amperes calculated curves (Fig. 10) show slightly higher temperatures than most of the test points. The slight increase in thermal conductivity of the insulation with the higher temperatures then obtaining but which were not allowed for in the calculations, may explain some of these differences.

For convenience, in Table III the principal points of interest are recorded. Attention is called to the close agreement between calculations and test for maximum temperature, minimum temperature and temperature at the end of the core; the exception being the maximum temperature at no-load. It will further be noted that there is but slight difference between the calculated minimum temperature, considering transverse flow only, and the minimum temperature by test. On the other hand there may be quite a large difference between the calculated maximum temperature,

TABLE III.

Heat Run	2600 Volts, N.L.	2400 V., 300 Amp.	2400 V., 383 Amp.
Calc. Max. Temp. Rise Par. Dis. of Iron Temp.	21.9	54.1	76.8
Calc. Max. Temp. Rise Const. Iron Temp.	21.1	52.0	74.8
Test Max. Temp. Rise (Slot No. 9)	28.5	53.3	73.5
Calc. Max. Temp. Rise Trans. Flow Only based on Max. Iron Temp.	27	63	90
Calc. Max. Temp. Rise Trans. Flow only Based on Av. Iron Temp.	23.5	57.3	82.8
Calc. Min. Temp. Rise Ends. (Const. Iron Temp.)	8.3	27.5	40.9
Test Min. Temp. Rise Ends. Approx. (Slot 21)	7.0	25.5	36.3
Calc. Min. Temp. Rise Ends. Trans. Flow only	7	24.6	36.7
Calc. Copper Temp. Rise End of Core (Const. Iron Temp.)	14.7	39.6	57.6
Test Temp. Rise End of Core (Slot No. 9.)	17.3	39.8	55

considering transverse flow only, and the maximum test temperature; especially is this the case at the 383-ampere load test when the temperature is figured on the basis of the maximum iron temperature (90 deg.) instead of 73.5 deg. rise). And this applies even though the machine is of medium length, and the copper,

at this load was worked at the fairly high nominal density of 2780 amperes per sq. in., with nearly negligible eddy current loss. (See the second paragraph under subject "Eddy Currents"). Thus, it may be misleading even in medium length machines, to ignore the longitudinal flow.

Further comparisons will be found under "The Average Coil Temperatures."

THE AVERAGE COIL TEMPERATURE

The temperature of the winding measured by resistance after shut-down is the average temperature at the particular time of measurement. Owing to the fact that there is necessarily a lapse of time between the removal of the load and the measurement of resistance, and since there is usually a difference in temperature between the copper and surrounding iron or air (the copper being usually at higher temperature), there is necessarily heat flow after shut-down and before the resistance is measured. Consequently, the average temeperature at the end of the heat run is usually higher than measured. At no-load the average temperature of the winding at the end of the run may be lower than the measured temperature, owing to the winding being at lower temperature than the iron.

Equation (**33**) enables the calculation of the average temperature (based upon constant iron temperature); with the use of equation (**33a**) the average temperature of the embedded part may be calculated. The results for the three heat runs are given in Table IV.

TABLE IV.

Heat Run	2600 Volt, N. L.	2400 V., 300 Amp.	2400 V., 383 Amp.
Calc. Av. Temp. Rise Embedded Part.	19.3	48.9	70.4
Calc. Av. Temp. Rise Entire Winding.	14.9	40.1	58.3
Av. Temp. Rise Test. (Res. Meas.)	15.5	35.3	44
Max. Temp. Rise Test. (Slot No. 9.)	28.5	53.3	73.5

An especial effort was made in these tests to allow as little time as possible to elapse between shut-down and measurement of resistance. (A Kelvin bridge was used). It will be noted, from an inspection of Table IV that the calculated average temperatures for both load runs were higher than test, whereas at no-load the reverse is the case, although the difference is slight.

Referring to Fig. 9, the average of the 300-ampere test curves for slots 9 and 21 (average of upper and lower curves) is 39 deg. rise, which is only 1.1 deg. lower than the calculated rise (40.1 deg.) The temperature rise by resistance was 35.3 degrees or 3.7 degrees lower than the test average rise. This difference is undoubtedly largely due to error in measurement due to loss of time.

The average rise from test curves on Fig. 10, (383-amperes load), as found by averaging the test curves for the coil in slots 9 and 21, is 54.1 degrees. The calculated average from the calculated curve is 58.3 deg., a difference of 4.2 deg. The temperature rise measured by resistance was 44 deg., or 10.1 deg. lower than actual. Thus there was an error, probably due to loss of time, of 23 per cent. It will therefore appear that the average temperatures as determined by resistance are not reliable.

The figures in Table IV show that the average temperature rise determined by resistance is certainly no means of judging the average temperature of the embedded part of the winding. Thus, in the 300-ampere run, if 1.1 deg. are deducted from the calculated rise $(48.9 - 1.1)$ to allow for the difference between the calculations and test, then the difference between the average embedded copper temperature rise and the measured average temperature rise of the entire winding is $(47.8 - 35.3 =) 12.5$ deg. At the higher load the difference is approximately $[(70.4 - 4.2) - 44 =]$ 22.2 deg. or about 50 per cent of the measured temperature rise. Certainly the resistance measurement affords no means of judging the maximum temperature, and an inspection of Table IV is sufficient proof of that statement without further comment.

THE INFLUENCE OF THE CORE LENGTH

It is felt that a paper on longitudinal and transverse heat flow would not be complete without illustrating the influence of core length upon temperatures, thereby helping to clarify the physical picture. It is believed that further assistance is obtained by showing the influence of the core length upon the watts generated, the watts transmitted transversely, and the watts transmitted longitudinally. It must be borne in mind that one set of curves of this character are not of general application, but to obviate this, sets of curves for various proportions of slots, copper section, insulation thickness, current density, etc., could be worked out, if believed to be sufficiently useful.

The particular proportions adopted were those of the turbo generator, for which the tests and calculations are given in this paper. The particular load selected was the one for 300 amperes 2400 volts. The conditions for constant average iron temperature of same value as in other calculations were assumed. Inasmuch as, in laying out a line of machines, it is usual to have some relation between pole pitch and core length, and since the length of the coil end is proportional to the pole pitch, the ratio of length of coil end to embedded portion was taken to be constant. Such assumption is not generally justifiable; as for instance, with changing length, (and proportionate diameter) the cooling of the end windings must also change (their cooling rate was taken to be constant); with increasing diameters the peripheral speed in such ma-

chine would eventually become prohibitive; and in commercial practise the length of core is frequently changed without changing the diameter.

In Fig. 12 will be found "Curves Illustrating the Influence of Core Length upon Temperature Rise." The particular machine described in this paper has a

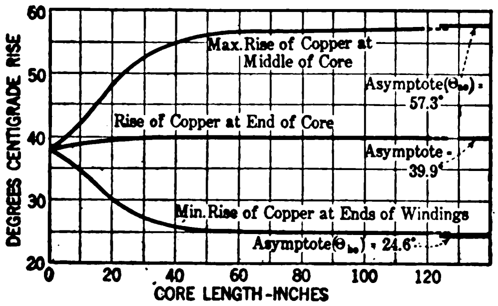

Fig. 12—Curves Illustrating Influence of Core Length Upon Temperature Rise

Based on constant ratio of length of ends to embedded parts.

nominal core length of (2× 14½ =) 29 in. as plotted in these curves. For these proportions, there is practically no change in temperature if the core length is increased beyond 50 in.

In Fig. 13 are plotted curves illustrating the losses

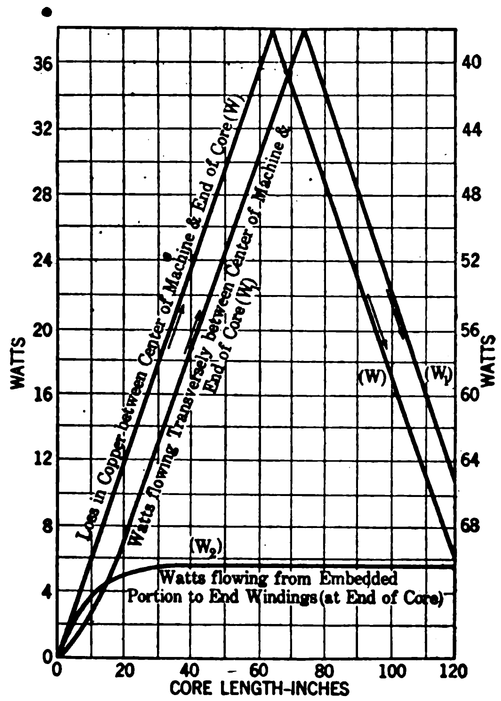

Fig. 13—Curves Illustrating the Losses in One-Half of the Embedded Portion of One Coil, and the Heat Paths for Same

Based on constant ratio of length of ends to embedded part.

in one half of the embedded portion of one coil, and the heat paths for same. Thus, for very short core lengths, most of the heat flows longitudinally, to be dissipated from the ends; for about 7-in. length of core about twice as much heat flows longitudinally as flows transversely; for 16-in. length the same quantities flow along the two paths; and beyond that, the longitudinal heat flow increases but little, whereas the transverse flow increases indefinitely. The total watts must always be the sum of the transverse and longitudinal flows, at any given length of core, and

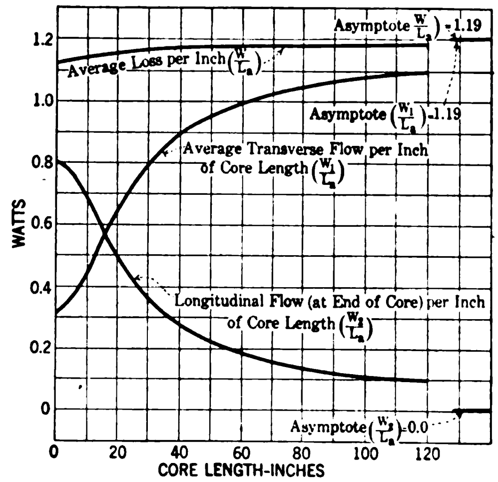

Fig. 14—Curves Illustrating the Losses in One Armature Coil and the Heat Paths per Inch of Core Length

Based on constant ratio of length of ends to embedded part.

would be directly proportional to the core length, but for the influence of temperature increasing the rate of loss generation.

In Fig. 14 the average rates of heat generation and the heat flows per inch of core length are plotted as functions of the core length. These curves of longitudinal and transverse flows illustrate the "usefulness" of the two for dissipating the generated heat; thus, as is well-known, the influence of the longitudinal

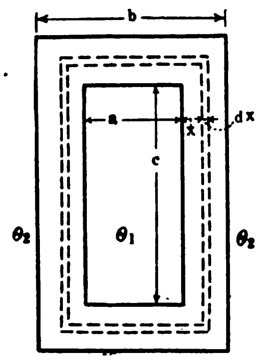

Fig. 15

flow is of maximum benefit for zero core length, and rapidly diminishes until for infinite length it becomes zero. The transverse flow is of minimum benefit for zero core length and approaches the same asymptote as the total generated watts approach; that is for infinite length all of the watts flow transversely.

APPENDIX

Area for Transverse Flow

Let Fig. 15 represent the section of a coil, the

single insulating wall being $\frac{b-a}{2}$. If W is the wattage flowing transversely, k the thermal conductivity $d\,\theta$ the temperature drop through small thickness $d\,x$, and the area of flow is $2\,[(a+2\,x)+(c+2\,x)]$, then:

$$W = -\,k\,2\,(a+c+4\,x)\frac{d\,\theta}{d\,x}$$

The negative sign appears because θ decreases with increasing x. Then:

$$\int_{\theta=\theta_1}^{\theta=\theta_2} d\,\theta = -\frac{W}{2\,k}\int_{x=0}^{x=\frac{b-a}{2}}\frac{d\,x}{a+c+4\,x}$$

$$(\theta_1-\theta_2) = \frac{W}{8\,k}\log_e(a+c+4x)\Big]_0^{\frac{1}{2}(b-a)}$$

$$= 0.288\;\frac{W}{k}\log_{10}\left(\frac{2\,b+c-a}{a+c}\right)$$

Now, figuring on *average* area basis,

$$W = k\left[2\left(a+\frac{b-a}{2}\right)+2\left(c+\frac{b-a}{2}\right)\right]\frac{\theta_1-\theta_2}{\frac{(b-a)}{2}}$$

Or,

$$(\theta_1-\theta_2) = \frac{W}{4\,k}\;\frac{(b-a)}{(b+c)}$$

Suppose the coil be intended for high voltage, and $a = 0.5$ in., $b = 1$ in., $c = 2$ in. By the more exact logarithmic expression, $(\theta_1-\theta_2) = 0.0419\frac{W}{k}$.

By the second, average area formula, $(\theta_1-\theta_2) = 0.0416\;\frac{W}{k}$. The difference is less than one per cent, thus justifying the use of the approximate equation. With thinner insulation, the error is less than with thick insulation.

AN OPPORTUNITY FOR COMMUNITY SERVICE BY PROFESSIONAL SOCIETIES

BY D. B. RUSHMORE AND R. F. EMERSON

The fundamental desire of individuals and organizations today is to render real service to the community of which they are a part. This is finding expression in many different forms and all over the country are being erected buildings of various kinds which have community service for their object. A large number of special organizations for this particular purpose are also coming into being.

There are however, many simple and easy ways in which existing means can be adapted to this end without special expensive buildings or special organizations and expense. Practically all of the large engineering professional societies in this country have local sections and have in the community many men who possess knowledge regarding science and engineering which is of great value and interest to the public if properly presented to them. Also most modern public schools have auditoriums or lecture rooms.

In connection with a plan which was proposed for Schenectady and which would involve a large building and the raising of a very considerable sum of money, it was felt by the authors that something could be done immediately to begin this work without waiting for any further developments.

A plan was devised whereby a series of lectures on science and engineering should be given to the public in simple, non-technical language under the auspices of the Schenectady Board of Education and the speakers furnished from the local sections of the American Chemical Society, Illuminating Engineering Society, American Society of Mechanical Engineers and the American Institute of Electrical Engineers.

As a result the following lectures were given:

November 29th, 1920, Chemistry and Some Common Things, by Prof. Edward Ellery.

December 13th, 1920, Light—Its Use and Abuse, in the Home, in the Street, and in the Place of Business, by S. L. E. Rose.

January 10th, 1921, Forty Years of Railroading, by S. T. Dodd.

January 24th, 1921, The X-Ray, by C. N. Moore.

January 24th, 1921, Submarine Detector Devices, by C. E. Eveleth.

March 14th, 1921, The Wonders of Electricity, by C. M. Ripley.

The first year's program has just been brought to a very successful end and it seems that such a valuable opportunity ought to be considered by all of the sections of the Institute and of other professional societies, and a great extension of this work should take place in the coming year. The attendance of the public showed that it greatly appreciated the opportunity to inform itself in connection with the various subjects presented and the experiment was, for a first try of this kind, unusually successful.

HIGH-VOLTAGE LIGHTNING ARRESTER TROUBLES

The Protective Devices Committee is making an attempt to learn of all unfavorable experiences which have occurred with all types of lightning arresters intended for normal operating voltage in excess of 7500 volts. It would like to get as full a statement as possible from all engineers regarding the defects of lightning arresters which they have in service and of their objections to the use of lightning arresters where such objections exist.

It would be of great assistance to the Committee if engineers having any information along this line would communicate with Mr. F. L. Hunt, Chairman, Subcommittee on Lightning Arresters, Turners Falls Power & Electric Co., Greenfield, Mass.

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of Electrical
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A. I. E. E. ANNUAL MEETING

The 370th meeting of the A. I. E. E. will be held in the Engineering Societies Building, New York, May 20th, 1921. This is the Annual Meeting of the Institute, at which the result of the annual elections is announced and the report of the Board of Directors is presented.

Following the business meeting there will be a lecture by Dr. Albert W. Hull of the Research Laboratory of the General Electric Company, the subject of which will be, "The Magnetron: A New Electric Valve." The lecture will be accompanied by experimental demonstrations.

FUTURE SECTION MEETINGS

Cleveland.—May 17, 1921. Hotel Statler. Annual Dinner Meeting. Subject: "Some Recent Developments in Scientific Research." Speaker: Mr. C. F. Kettering, of The Dayton Engineering Laboratories.

Erie.—May 10, 1921. Subject: "Energy." Speaker: Dr. Charles P. Steinmetz.

Philadelphia.—May 9, 1921. "Celluloid Night," featuring the Spirograph.

San Francisco.—May 27, 1921. Subject: "220,000 Volt Transmission." This meeting will be in the nature of a symposium of results of studies and investigations by different speakers, and will also be descriptive of some of the equipment to be used for this transmission voltage now contemplated by two of the largest companies on the Pacific Coast. Professor Ryan will give the main paper.

Vancouver.—May 6, 1921. Subject: "Electric Power in Pulp and Paper Mills." Speaker: Mr. T. H. Crosby.

June 3, 1921. Annual Meeting. Election of officers.

Baltimore.—May 20, 1921. Subject: "Transformers". Speaker: Mr. J. T. Corrin, of the Pittsburgh Transformer Company. The meeting will be held in the new quarters of the Engineers Club in the Merchants & Manufacturers Building.

PITTSBURGH MEETING, APRIL 16, 1921

The joint meeting of the A. I. E. E. and the Association of Iron and Steel Electrical Engineers, which constituted the 369th meeting of the Institute, was held in Pittsburgh, in accordance with the announced program, on Saturday, April 16, 1921.

A special train conveyed about 800 members from the Union Station, Pittsburgh, to the Colfax Power Station of the Duquesne Light Company, arriving there about 11:00 a. m. Many other members reached the plant by motor.

Every facility for the inspection of every part of the plant, with or without guides, was afforded to the visiting members, after which a buffet luncheon was served to the entire party at the plant.

Afternoon Session

From the Power Station, all returned to Carnegie Hall, North Side, Pittsburgh, where the first technical session of the day was held at 3:00 p. m. Professor B. C. Dennison, Chairman of the Pittsburgh Section of the Institute, called the meeting to order and presented President Berresford as presiding officer; President E. S. Jefferies, of the A. I. & S. E. E., was also upon the platform.

After brief remarks, President Berresford called upon Messrs. C. W. E. Clarke and D. L. Galusha, of the Dwight P. Robinson Company, who presented their paper on "The Colfax Power Station of the Duquesne Light Company, Pittsburgh."

An interesting discussion followed, participated in by Messrs. C. S. Cook, G. F. Brown, F. C. Hanker, George Bell, C. F. Hirshfeld, F. Hodgkinson, W. T. Snyder, R. H. Keil, F. E. Leahy, E. C. Stone and the authors. Lack of time prevented further discussion but many others who had signified their intention to participate were requested to submit their discussion later for publication.

Dinner

An informal dinner, attended by over 700 members and guests of the two Societies, was held at the William Penn Hotel, at 6:00 o'clock p. m., at the close of which brief addresses were made by President Berresford of the Institute, President E. S. Jefferies of the A. I. & S. E. E., and President A. W. Thompson of the Philadelphia Company.

Evening Session

A second technical session followed immediately after the dinner, the presiding officer being President Jefferies of the A. I. & S. E. E. The papers presented were: "The Frequency Problem in the Steel Industry" by B. G. Lamme, Chief Engineer, Westinghouse Electric & Manufacturing Company; "The Interconnection of Steel Mill and Central Power Houses, and Its Relation to Frequency" by D. M. Petty of the Bethlehem Steel Company.

The discussion which followed was participated in by Messrs. R. B. Shover, James Farrington, L. F. Galbreith, Frank Leahy, A. C. Cummins, George E. Stoltz and the authors.

The entire meeting was enthusiastic and successful in every way, and reflects credit upon the joint committee of arrangements, consisting of representatives of both Societies.

SUNSET ON GREAT SALT LAKE

Annual and Pacific Coast Convention

SALT LAKE CITY, UTAH, JUNE 21-24, 1921

An unusual opportunity is offered Institute members this year to combine attendance at the Thirty-Seventh Annual Convention, Salt Lake City, Utah, June 21-24, 1921 with a pleasure sight-seeing trip among the natural wonders of the Yellowstone, the Grand Canyon, the Rockies and the Pacific Coast.

The Convention, itself, promises to exceed in interest previous annual meetings both from a technical viewpoint and as an opportunity to increase acquaintanceship among the members of the electrical engineering profession, and to renew acquaintance with old friends. The local arrangements at Salt Lake City provide a happy combination of business and recreation so adjusted that the inclinations of all may be satisfied. Twenty-four subcommittees, with their work directed and coordinated by the Convention Committee, H. T. Plumb, Chairman, insure careful attention to all necessary details. Arrangements to attend may be made with the full assurance that nothing has been overlooked to make this year's Convention a signal success. Ladies are particularly invited and will find the afternoon and evening events of particular interest.

Institute headquarters will be located at the Hotel Utah and all technical sessions will be held there.

An outline of the program follows:

Tuesday, June 21

The convention will open on Tuesday morning, June 21, with the Annual Presidential Address by Arthur W. Berresford. A technical session, with the presentation of several papers, under the auspices of the Electrical Machinery Committee will follow. Directly succeeding the technical session a luncheon for the Section Delegates is scheduled. This will serve as an opportunity for the delegates to become acquainted and to discuss points of general interest. Tuesday afternoon there will be a trip on foot past the most interesting historical Latter Day Saints buildings, followed by a short lecture and organ recital in the Tabernacle. At 7:00 p. m. an auto trip has been arranged to reach the famous Wasatch Boulevard at sunset and later to Capitol Hill. A return will be made to the Hotel Utah in time for an informal reception at 9:30 p. m.

Wednesday, June 22

Wednesday morning the second technical session will be held under the auspices of the Industrial and Domestic Power Committee. For the forenoon a special entertainment for the ladies has also been scheduled with perhaps a luncheon at the Literary Club. On Wednesday afternoon a special train will leave from the Oregon Short Line depot at 12:30 p. m. over the Bingham and Garfield Railroad. Lunch will be served on the train. This trip in addition to magnificent views of Great Salt Lake and Salt Lake Valley will provide an opportunity for Institute members to inspect a typical mining canyon, surface workings of a big mine with mills and smelters. On Wednesday evening there will be a meeting of the Section Delegates and Officers of the Institute and which will be open to all interested. It is hoped Prof. Karapetoff will render a piano recital, a feature which will particularly appeal to those members who have heard his recitals at previous conventions.

Thursday, June 23

Thursday morning, the technical session will be under the auspices of the Transmission and Distribution Committee. The Board of Directors will meet at luncheon, Thursday noon, and follow the luncheon with a short business meeting. Thursday afternoon is assigned to an automobile trip to the Utah Power and Light Company's Terminal Station, the terminus of three 130,000-volt transmission lines, and said to be the largest outdoor substation in the world. Arrangements will also be made for those who wish to devote the time to golf or tennis. For the after-dinner entertainment Dr. Broaddus will deliver an illustrated lecture on the wonderful canyons of Utah.

Friday, June 24

Friday morning, June 24, is assigned for the presentation of various miscellaneous technical papers. On Friday afternoon the finals of the Golf and Tennis Tournaments will be held. Bathing at Saltair Beach is scheduled from 5:00 p. m. to 7:00 p. m., followed either by a dinner in the Ship Cafe or an old fashioned basket picnic with dancing for those who wish it.

Saturday, June 25

On Saturday various *After Convention Trips* have been planned to local points of engineering interest, such as electric railways, power stations, pumping plants, smelters, mills, etc. Trips can also be made to Mountain Parks, Canyons, Brighton, Park City, and Bird Island or to the Shoshone Falls, Bryce Canyon, Zion Canyon, the Grand Canyon and Yellowstone Park.

TENTATIVE PROGRAM OF TECHNICAL SESSIONS

Tuesday, June 21

10:00 A. M.

President's Address—by Arthur W. Berresford.

Technical Committee Reports.

Hydroelectric Developments at Niagara Falls—by J. L. Harper.

Modern Developments in Waterwheels—by W. M. White.

Wednesday, June 22

9:30 A. M.

Economic and Engineering Problems of 220-Kv. Transmission—by L. E. Imlay.

Voltage and Power Factor Control of 66,000-Volt Transmission Lines Connecting Two Generating Stations.—by R. Bailey.

Symposium on Long-Distance Transmission Systems—by F. G. Baum, W. W. Lewis, and L. L. Elden.

Modern Production of Suspension Insulators—by E. H. Fritz and G. I. Gilchrest.

Thursday, June 23

9:30 A. M.

Voltage and Current Harmonics Caused by Corona—by F. W. Peek, Jr.

A Solution of the Porcelain Insulator Problem—by E. E. F. Creighton and F. L. Hunt.

Transformers for Interconnecting High-Voltage Systems or for Feeding Synchronous Condensers from a Tertiary Winding—by J. F. Peters and M. E. Skinner.

Electric Strength of Air under Continuous Potentials and as Influenced by Temperature—by J. B. Whitehead and F. W. Lee.

Friday, June 24

9:30 A. M.

Synchronous Motors for Ship Propulsion—by E. S. Henningsen.

Magnetic Properties of Compressed Powdered Iron, by Buckner Speed and G. W. Elmer.

Heat Losses in Conductors in A-C. Machines—by W. V. Lyon.

Three of the papers listed are published in this issue of the Journal, the balance will appear in the June and later issues.

Sports

In addition to the regular time allotted to sports during the convention, it will be possible for members desiring to devote more attention to this feature to arrange for additional tennis or golf. The gymnasium of the Latter Day Saints immediately adjacent to the hotel will probably be available for the free use of members and will afford special bathing and exercise at any time of day.

Hotel Reservations

All members expecting to attend the convention should if possible, make their hotel reservations immediately.

Convention Headquarters—Hotel Utah, with State Capital in Background

Transportation

It is extremely important that members consult their local railroad agents and decide on the exact and most advantageous route to and from Salt Lake City for their purpose, and make their reservations as early as possible. Summer Excursion Rates take effect June 1st offering round trip fares, considerably below those now prevailing. These tickets permit stop-overs en route and are good until about October 31st.

Arrangements to visit Yellowstone Park, the greatest scenic drawing card in the western United States, can be made either en route to or en route from the convention. The actual round trip fare via Yellowstone will not exceed that to Salt Lake City and return, direct, the only additional expense being for transportation and accommodations in the park. All expenses for the 4½ day trip amounting to \$45.00 via auto and camp route and \$54.00 via auto and hotel route.

As a very large number of eastern members will of necessity pass through Chicago, it is pointed out that the last train leaving Chicago in time to reach Salt Lake City for the first Convention

session, Tuesday morning, June 21st, is train No. 19 over the Chicago and North Western R. R. and Union Pacific R. R. This train leaves Chicago 10:30 A. M., Sunday, June 19th, arriving in Salt Lake 8:20 A. M. Tuesday June 21st. The round trip fare, (summer excursion rates, all roads) from Chicago to Salt Lake City will be $77.76 Persons wishing to go over this route on the train mentioned above should communicate with E. E. Bogardus, City Agents, Chicago & Northwestern R. R., 148 S. Clark St., Chicago, Ill., and obtain their Pullman reservation; additional cars will be added to the train to meet the demand.

Those wishing to return via Kansas City or St. Louis can make the trip via the Denver & Rio Grande R. R. and the Missouri Pacific passing through the magnificent Royal Gorge.

It is assumed that some members will wish to extend their trip to the Pacific Coast and in that event should purchase Pacific Coast Summer Excursion tickets at their initial point with stop over at Salt Lake City; similarly members from the Pacific Coast may obtain summer excursion rates to points in the East with stop over at Salt Lake City.

Temple Block, Salt Lake City

A. I. E. E. DIRECTORS MEETING

APRIL 16, 1921

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the Colfax Power Station of the Duquesne Light Company, Colfax, Pa., on Saturday, April 16, 1921, at 11:00 a. m.

There were present: President A. W. Berresford, Milwaukee; Vice-Presidents L. T. Robinson, Schenectady, E. H. Martindale, Cleveland; Managers Wm. A. Del Mar, New York, Wilfred Sykes, Chicago, F. D. Newbury, Pittsburgh, H. B. Smith, Worcester, James F. Lincoln, Cleveland; Secretary F. L. Hutchinson, New York.

Reports were presented of meetings of the Board of Examiners held April 1 and 14, 1921; and the actions taken on applications at those meetings were approved.

The Directors ratified the action of the Executive Committee, under date of April 8, in approving applications for admission and transfer, as follows: 200 Students were ordered enrolled; 425 applicants were elected to the grade of Associate; 12 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 21 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

The Meetings and Papers Committee reported, outlining plans for the Institute meeting of May 20 and the Annual and Pacific Coast Convention, June 21-24; also recommending that approval be given to a request of the Marine Committee for a joint meeting to be held with the Society of Naval Architects and Marine Engineers, on Thursday afternoon, November 17, 1921, in New York, during the annual meeting of that society. The report was accepted and the recommendations embodied therein approved.

A petition for the formation of a Connecticut Section, which had been approved by the Chairman of the Sections Committee, was presented and the desired authority granted.

Authority was granted for the organization of a Student Branch at the University of Southern California, Los Angeles.

A communication from the American Engineering Standards Committee was presented, inviting the Institute to become Joint Sponsor with a number of other societies for the unification of specifications for insulated wires and cables for other than telephone and telegraph use. The invitation was accepted and the President was authorized to appoint two delegates to the proposed sectional committee.

An invitation from the American Engineering Standards Committee to send one representative, and any other members of the Institute who may be interested, to conferences regarding the formulation of national symbols for electrical equipment of buildings, was accepted; this request being the outcome of a number of previous conferences between representatives of the National Association of Electrical Contractors and Dealers and the American Institute of Architects, which bodies had formulated a code of symbols in 1911.

In acceptance of an invitation from the University of Minnesota to the Institute to be represented at the inauguration of Lotus Delta Coffman as President of the University, on May 13, 1921, Professor F. W. Springer, of the University of Minnesota, was designated to represent the Institute on that occasion.

In addition to these actions many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the Journal under suitable headings.

AMERICAN ENGINEERING COUNCIL

MEETING IN PHILADELPHIA, APRIL 16

Herbert Hoover Resigns as President

Herbert Hoover has resigned as president of American Engineering Council of the Federated American Engineering Societies. Mr. Hoover's resignation was submitted and accepted as the closing action of the sessions of the council held April 16 at the Engineers Club of Philadelphia. Mr. Hoover gave as his reasons the fact that American Engineering Council by its constitution was necessarily engaged in furthering national activities which involve legislation; and that he as a member of the executive branch of the government could not consistently direct such activity as an officer of American Engineering Council.

The council, in a resolution of regret at Mr. Hoover's retirement, voted its appreciation of Mr. Hoover's leadership during the organization period of the council and his initiation of policies and effort.

The meeting of the council was one of the most important yet held and progress was noted in every direction. The sessions were opened by Calvert Townley as presiding officer. Later Mr. Hoover took the chair and presided over the greater part of the deliberations. Members attending were:

Herbert Hoover, president; Calvert Townley, vice president, representing A. I. E. E.; J. Parke Channing, vice president, representingA. I. M. M. E.; E. Ludlow, president A. I. M. M. E.; F. J. Miller, past president A. S. M. E.; M. L. Cooke, Taylor Society; Wm. McClellan, A. I. E. E.; A. S. Dwight, A. I. M. M. E.; A. M. Greene, A. S. M. E.; Dean of the School of Engineering, Troy Polytechnic Institute; S. H. McCrory, A. S. Agricultural Engineers; W. W. Varney, Baltimore Engineers Club; J. F. Oberlin, Cleveland Engineering Society; O. H. Koch, Technical Club of Dallas; D. S. Kimball, vice president, Dean of School of Engineering of Cornell, A. S. M. E.; Gardner S. Williams, Engineering Society of Grand Rapids; C. F. Scott, A. I. E. E., School of Engineering, Yale University; W. B. Powell, Buffalo Engineering Society; W. E. Rolfe, vice president, Associated Engineering Societies, St. Louis; L. B. Stillwell, A. I. E. E.; L. P. Alford, A. S. M. E.; H. W. Buck, past president A. I. E. E.; E. S. Carman, A. S. M. E., Cleveland; Philip N. Moore, A. I. M. M. E., Washington.

Elimination of Waste in Industry

One of the most important matters before the council was the report of the Committee on Elimination of Waste in Industry, of which J. Parke Channing is chairman and L. W. Wallace, executive secretary of the council, vice chairman. The committee has been conducting an assay of waste in principal industries for more than three months under the direction of Mr. Wallace. The work has been conducted from temporary headquarters in New York. The first reports of the assay will be ready in June. These reports are being put into final form at the permanent offices of the council in Washington, 719 Fifteenth Street.

E. E. Hunt, who has been on Mr. Hoover's staff, and who has been indentified with the Elimination of Waste in Industry Committee since its formation, has been retained to direct the work of that committee until its completion. He will be largely responsible for collating and editing the report. This work will require two or three months.

Employment Service

The report of the Executive Secretary Wallace gave the results of a special study of the Employment Service made by Mark M. Jones. Plans for broadening the scope of the service were recommended and adopted.

Patent Legislation

In submitting the report of the Patents Committee, headed by Edwin J. Prindle, Mr. Wallace noted the favorable attitude of members of Congress toward patent legislation sponsored by the council. Every effort will be made to bring about necessary Patent Office reforms at the present session of Congress.

Licensing of Engineers

Dealing with the licensing and registration of engineers, Mr. Wallace's report said that this had been a very active feature of the council's legislative program. "A number of states have bills before their legislatures on licensing of engineers," Mr. Wallace stated. "We have had representatives attend hearings on such bills from several states. We have emphasized that the position of the council is that we do not believe that such legislation is necessary, but where such is to become a fact we are interested in seeing that the legislation passed is of such character as to be beneficial both to the public and the engineering profession."

Other Activities

Other matters discussed by the secretary were publicity, in which splendid progress was recorded, and which is now in charge of James T. Grady, Director of the Department of Public Information, Columbia University; petitions of the council for the appointment of an engineer as Assistant Secretary of War, in which favorable action was not obtained, and for the appointment of an engineer to the Interstate Commerce Commission, which is still under consideration; a request from the engineers in the public health service for cooperation in legislation that will give them professional standing, favorable action being recommended by the secretary; and closer relations with the government departments both in giving appropriate counsel and in obtaining information which in the form of a bulletin service is being sent out in increasing volume to engineers in member societies.

Public Affairs

The report of the Public Affairs Committee headed by J. Parke Channing was adopted. This report recommended continuance of the public works campaign, to promote which the organization of the National Public Works organization will be continued. The Committee on New York State Government Reorganization reported striking progress. An elaborate report has been submitted to Governor Miller and the Judiciary Committees of both houses of the legislature presenting the engineering point of view as to the making over of the state government. This report has been widely noticed in the press and is having substantial influence on the question of remoulding the state administrative systems.

The executive secretary of the council has been appointed on the Advisory Board to the Board of Surveys and Maps to succeed A. D. Flinn, who represented old Engineering Council. Mr. Wallace also recorded requests for support from the American Engineering Standards Committee in securing legislation to obtain: Official cooperation by the government departments; payment by the government of its own quota of expenses; official recognition of approved specifications in government purchases; government publications of translations of approved specifications for the promotion of foreign trade.

New Member Societies

Three new member societies have joined the Federation since the last meeting. They are the Boston Society of Civil Engineers and the Engineering Societies of Milwaukee and Duluth.

Other important additions to the Federation's swelling membership and influence are expected to be announced before July 1.

Next Meeting in St. Louis

The next meeting of the Council will be held in St. Louis, June 3. This meeting will probably be the most important yet held by the society. It will synchronize with the report on the waste assay and will mark another progressive stage in the work of organization. For the intervening period Mr. Wallace and his associates mapped out a vigorous campaign of constructive effort.

DELEGATION OF AMERICAN ENGINEERS TO PRESENT JOHN FRITZ MEDAL TO SIR ROBERT HADFIELD

To express the obligation which the world owes to the engineers of Great Britain for the part they played in winning the war, the engineers of America will send a mission to London this summer. The mission, consisting of nationally known engineers and representing the National societies of Civil. Mining, Mechanical and Electrical engineers, will present the John Fritz Medal to Sir Robert Hadfield at the opening meeting of the British Institution of Civil Engineers on June 29.

The inability of Sir Robert to come to the United States to receive the medal moved the trustees of the Board of Award to make the ceremony of presentation in England the occasion for an international expression of appreciation.

The deputation to England will consist of a representative of each of the four Societies represented on the John Fritz Medal Board of award as follows:

Charles T. Main of Boston, the American Society of Civil Engineers; Colonel Arthur S. Dwight of New York, the American Institute of Mining and Metallurgical Engineers; Ambrose Swasey of Cleveland, the John Fritz Medal Board of Award and the American Society of Mechanical Engineers: Dr. F. B. Jewett of New York, the American Institute of Electrical Engineers. Dr. Ira N. Hollis, President of the Worcester Polytechnic Institute and past president of the American Society of Mechanical Engineers, will accompany the deputation and bear the message from the American engineers.

The John Fritz Medal is presented for achievement in applied science as a memorial to the engineer whose name it bears. The medal was awarded to Sir Robert this year because of his invention of manganese steel. It was originated by the professional associates and friends of John Fritz of Bethlehem, Pa., on Aug. 21, 1920, his eightieth birthday, to perpetuate the memory of his achievements in industrial progress.

INSTITUTE PRIZES

As announced in the April issue of the JOURNAL, the Board of Directors of the Institute has established two Institute prizes to be awarded to authors of worthy papers, and the Committee on Coordination of Institute Activities was charged with the duty of formulating the procedure to be followed in making the award. This Committee held a meeting on March 11th and prepared its recommendations, which were submitted to, and approved by, the Board of Directors at a meeting held in Pittsburgh, April 16th. The following extracts from the report of the Committee embody the essential features of the procedure to be followed:

THE FIRST PAPER PRIZE

(1) This prize, established by the Board of Directors of the Institute, January 14, 1921, shall consist of $100 cash, and a suitable certificate, to be awarded each year to the author of the paper which is designated by a duly authorized committee of award as the most worthy original paper, presented during the year at a meeting of any Section of the Institute, by a member of the Institute who has never before presented a paper before the Institute or any of its Sections.

(2) To be considered for competition, the author, or an officer of the Section at which the author's paper was presented, shall submit the paper to the committee of award, by means of a written communication to the Secretary of the Institute, prior to January 15 of the year following the calendar year in which the paper was presented.

(3) Papers by joint authors are eligible for this competition, provided both authors meet the qualifications, in which case the prize shall be divided equally between the authors.

(4) The award shall be made by a committee consisting of the Chairman of the Meetings and Papers Committee as chairman, and the chairmen of the technical committees of the Institute, prior to June 1.

(5) The prize shall be presented at the Annual Convention of the Institute.

(6) The paper shall be published in the monthly JOURNAL or annual TRANSACTIONS of the Institute, or both.

(7) Manuscripts shall be submitted in duplicate and shall be typewritten on one side of paper of approximately 8½ by 11 inches. The letter entering the paper in the competition need not be accompanied by duplicate copies of the paper, provided suitable manuscript copies in duplicate have been submitted previously.

THE TRANSMISSION PRIZE

(1) This prize, established by the Board of Directors January 14, 1921, shall consist of $100, and a suitable certificate, to be awarded each year to the author of the paper which is designated by a duly authorized committee of award as the most worthy paper dealing with the art of transmitting electrical energy over considerable distances, presented during the year by a member of the Institute, at a meeting of the Institute or of any of its Sections.

(2) To be considered for competition, the author shall submit the paper to the committee of award, by means of a written communication to the Secretary of the Institute, prior to January 15 of the year following the calendar year in which the paper was presented.

Paragraphs three to seven, as printed above under the heading "The First Paper Prize", also apply to this award.

As stated in the April issue of the JOURNAL, papers presented before the Institute during the calendar year 1921 will be eligible for these competitions.

AMERICAN ENGINEERING STANDARDS COMMITTEE

ANNUAL REPORT ISSUED

Although the American Engineering Standards Committee has been actively at work for only slightly more than one year and much of the time and effort of the Committee has necessarily been spent in laying a basis for work the fruition of which will require at least two or three years, yet considerable progress has already been made in the unification of the more important standards and in overcoming the confusion that was being produced by numerous organizations (more than 100) that hitherto published engineering standards without systematic cooperation among themselves.

Prior to December 31, 1920, there had been approved by the Committee "Tentative American Standard Specifications and Tests for Portland Cement", "Tentative American Standard Specifications for Fire Tests of Materials and Construction," and "American Standard Pipe Threads." Moreover there had been submitted for approval by the Committee the "National Electrical Code" as an American Standard, and "Standard Test for Toughness of Rock," "Standard Method of Distillation of Bituminous Materials for Road Treatment," and "Standard Method of Sampling Coal," as Tentative American Standards, with the "Safety Code for Head and Eye Protection" submitted for approval as "Recommended American Practise."

The Committee itself is composed of 47 members representing 17 bodies or groups of bodies, including six national engineering societies, five Governmental departments and 13 national industrial associations. Its function is merely to see that each body or group concerned in a standard shall have opportunity to participate in its formulation which is in the hands of a working committee, technically called a "sectional committee." Each sectional committee is organized by, and under the leadership of, one or more of the principal bodies interested, such bodies being known as "sponsors." Sponsorships have been arranged for the following projects which were under way by the beginning of this year:

Electrical Projects. "Rating of Electrical Machinery" and "Terminal Markings for Electrical Apparatus".

Mechanical Projects. "Ball Bearings," "Plain Limit Gages," "Gears", "Machine Tools," "Nut and Bolt Heads," "Pipe Flanges and Fittings", "Screw Threads," "Shafting".

General Projects. "Passenger and Freight Elevators," "Color Scheme for Pipe Line," "Steel Shapes," "Zinc Ores and Zinc."

Safety Codes. "Aviation Safety Code," "Construction Work," "Electrical Fire Code," "Electrical Safety Code," "Floor Openings, Railings Toe Boards," "Foundries", "Gas Safety Code," "Grinding Wheels," "Head & Eye Protection," "Ladder Code" "Lighting Code," "Lightning Protection," "Logging Operations and Sawmill Machinery," "Machine Tools," "Mechanical Transmission of Power," "Paper and Pulp Mills," "Electrical Power Control," "Power Presses," "Mechanical Refrigeration," "Industrial Sanitation," "Stairways, Fire Escapes and Other Exits," "Textiles," "Ventilation," and "Woodworking Machinery."

As will be seen from the above lists, an important part of the Committee's work relates to safety codes. On December 8, 1920 at a conference at which more than 100 organizations were represented it was unanimously voted that a comprehensive program of safety codes should be undertaken, to be carried out under the auspices of the American Engineering Standards Committee to insure proper coordination and elimination of overlap, etc. Active work is now in progress on 24 such codes with hearty cooperation among the state commissions, associations of insurance companies, national engineering societies, manufacturers' and industrial associations, labor and civic organizations, and technical bureaus of the Federal Government. As is true of all work under the auspices of the American Engineering Standards Committee, such of the bodies as are interested in the particular code in question are represented in the committees responsible for the formulation of each code.

Copies of the Report may be obtained by addressing a request to the American Engineering Standards Committee, 29 West 39th Street, New York.

AUTOMOBILE HEADLIGHTING SPECIFICATIONS

The Illuminating Engineering Society has submitted its "Automobile Headlighting Specifications" to the American Engineering Standards Committee for approval. The specifications are submitted in accordance with the special provision in the procedure of the Committee, under which important standards in existence prior to 1920 may be approved without going through the regular process followed in new work.

The specifications have been adopted in their essential details by the States of Wisconsin, Connecticut and Maryland, and by the Province of Ontario, and have been endorsed by the Standards Committee of the Society of Automotive Engineers by the International Traffic Officers' Association, and by the conference committee on Uniform Vehicle Laws representing some 30 different organizations under the auspices of the National Safety Council.

The Headlighting Specifications of the Illuminating Engineering Society may be found in the *Transactions* of the Society, Vol. XV, No. 4, June 10, 1920. Copies may also be obtained from the American Engineering Standards Committee, 29 West 39th Street, New York. Price 10 cents.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute Records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Leo Arany, Room 201 Parkway Bldg., Broad & Cherry Street, Philadelphia, Pa.

2.—De Los De Tar, 411 East 15th Street, Kansas City, Mo.

3.—George W. Huey, R. F. D. No. 5, Wilkinsburg, Pa.

4.—Major, J. E. H. Stevenot, c/o Bureau of Insular Affairs, War Dept., Washington, D. C.

5.—Murel A. D. Summer, c/o Pittsburgh Transformer Co., Pittsburgh, Pa.

PERSONAL MENTION

E. F. W. Alexanderson, chief engineer, Radio Corporation of America, is in Europe on a business trip.

Clarence J. Berry of Paris, France, has gone into business for himself, specializing in illuminating engineering work in France.

Lloyd E. Oneal has left Dwight P. Robertson & Co., Inc., New York, and is now located with Chas. Cory & Son, Inc., New York.

F. J. Robbins, formerly of Tacoma, Washington, has been since April 1st with Grays Harbor Railway, Light and Power Company, Aberdeen, Washington.

Walter D. Royer has left his position as branch manager in Pittsburgh of the Black & Decker Mfg. Co. of Baltimore, to become sales engineer for McGraw Company, Sioux City, Iowa.

P. G. Agnew, secretary of the American Engineering Standards Committee, sailed for England in April to attend a conference of secretaries of national standardizing bodies held in London.

Albert Kingsbury, who was formerly located in the Oliver Building, Pittsburgh, is now conducting his engineering business under the name of Kingsbury Machine Works, located at Frankford, Philadelphia, Pa.

George S. Davis, in charge of the radio service of the United Fruit Co., has been elected a director of the Radio Corporation of America. Mr. Davis is also president of the Wireless Specialty Apparatus Co., of Boston, Mass.

J. J. Gaffey, assistant engineering manager of the Harry M. Hope Engineering Company, Boston, announces that the company has established offices in the Dominion Express Building, Montreal, to handle its Canadian business.

Harry B. Joyce, formerly a major in the Construction Division of the army, has resigned as a member of the firm of Johnson and Benham, Inc., consulting engineers, to assume charge of the engineering work of the Centrifugal Fan Company Newark, N. J.

Robert J. Mailhouse and Joseph N. Golding have severed their connections with the Interborough Rapid Transit Company of New York City and have opened an office in the Chamber of Commerce Building in New Haven, Conn., where they will practise engineering under the name of Mailhouse & Golding, Incorporated.

Howard M. Raymond has been appointed as acting president of the Armour Institute of Technology to fill temporarily the vancancy caused by the death of Dr. F. W. Gunsaulus. Acting president Raymond has been connected with the Armour Institute for the past twenty-six years, and has served as dean of engineering since 1903.

Frederick G. Simpson announces the establishment of his offices in the L. C. Smith Building, Seattle, Washington. Mr. Simpson is an experienced electrical engineer, formerly connected with Kilbourne & Clark Mfg. Co., Seattle, as chief engineer and general manager. During the war he was officer in charge of radio material activities, United States Navy, on the North Atlantic Coast.

F. B. JEWETT, chief engineer of the Western Electric Company, has been elected a vice-president and director of his company. He will continue his present duties in charge of the technical forces. Dr. Jewett is well-known for his contributions in the telephone field; the perfection of wireless telephony is one of the undertakings completed under his direction. During the war he was a Lieutenant-Colonel in the Signal Corps, and was decorated with the Distinguished Service Medal. As an advisory member of the Special Submarine Board of the Navy he contributed much toward the perfection of devices for detecting hostile submarines. Dr. Jewett is a Fellow and a former vice-president of the INSTITUTE.

JAMES R. BIBBINS has resigned as supervising engineer of the Arnold Company, Chicago, to accept an appointment as manager of the Department of Transportation and Communication of the United States Chamber of Commerce, Washington, D. C. This new Department will have a wide range of activities, covering shipping, ocean and inland; steam and electric railroad transportation, air transportation, cables and telegraphs, postal facilities, and highways. Mr. Bibbins brings to it a wide experience in the transportation field, including over ten years' association with Bion J. Arnold, consulting engineer, and president of the Arnold Company, in consulting work dealing with the transportation problems of a number of the large cities of the United States and Canada. He is a Fellow of the INSTITUTE, and has been serving as chairman of the Chicago Section.

OBITUARY

LESTER GRAY FRENCH, for thirteen years editor and manager of "Mechanical Engineering," the journal of the American Society of Mechanical Engineers, and assistant secretary of the society, died on April 18th, 1921, at the French Hospital, New York City, from septic poisoning following an operation. Mr. French was born in Keene, N. H., in April 1869, and was graduated from the Massachusetts Institute of Technology in 1891. After serving for a year as draftsman with the Cranston Printing Press Company he took up the teaching of mechanical engineering until 1895, when he entered the employment of the Builders Iron Foundry as assistant to the superintendent. In 1897 he became editor-in-chief of "Machinery," and continued in this position for about ten years, resigning to take up the publication of technical books, among them being one of the earliest treatises on the steam turbine, of which he was the author. He was made editor of the publications of the American Society of Mechanical Engineers in 1908. Mr. French was a member of the American Society of Mechanical Engineers, and also of the Engineers Club of New York. His home was in White Plains, N. Y.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (MARCH 1-31, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or text of the book.

All books listed may be consulted in the Engineering Societies Library.

ARCHIMEDES.

By Sir Thomas Heath. Lond., Society for Promoting Christian Knowledge; N. Y., The Macmillan Co., 1920. (Pioneers of Progress), 58 pp., front., 7 x 5 in., cloth $.80.

Sir Thomas Heath has written an interesting brief account, ample for the general reader, of the contributions of Archimedes to mathematics and mechanics, and the significance of his work.

BELTS FOR POWER TRANSMISSION.

By W. G. Dunkley. Lond., and N. Y., Sir Isaac Pitman & Sons, Ltd. (Pitman's technical primer series.) 104 pp., diagrams, 7 x 4 in., boards, $1.00.

Contents: Belt materials and types of belts.—Power transmitted by belts.—The "Lenix" system of belt driving.—Length of belts.—Steel belts.

This is a small volume, for students and designers, presenting and discussing the factors and considerations involved in belt driving. Tables of use to designers are included.

THE COMPLETE AIRMAN.

By G. C. Bailey. N. Y., E. P. Dutton and Co. 269 pp., plates, diagrams, 9 x 6 in., cloth. $6.00.

This book discusses aviation in a more or less elementary fashion, for those generally interested in its technical aspects, pilots, mechanics, and managers of commercial enterprises connected with aviation. The theory of flight, the care and construction of machines, practical flying, and auxiliary equipment are considered in a non-technical manner.

COMPRESSED AIR.

By Theodore Simons. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 173 pp., illus., tables, 9 x 6 in., cloth. $2.00.

This treatise is intended to give the student such an insight into the natural laws and physical principles underlying the production, transmission and use of compressed air, as will enable him to comprehend the operation of the various appliances used for this purpose and to judge of their merit. The present edition has been carefully revised and partly rewritten.

COPPER REFINING.

By Lawrence Addicks. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 211 pp., illus., tables, 9 x 6 in., cloth. $3.00.

Contents: Metal losses.—Metals in process.—Tank resistance.—Current Density.—Current efficiency.—Impurities.—By-products.—Furnace refining.—The requirements of re-

fined copper.—Copper from secondary material.—The power problem.—Elements of design.—Application to other fields.
Electrolytic copper refining was for so many years conducted under conditions of strict commercial secrecy that but little has been published regarding the principles of operation, as distinct from descriptions of individual plants.
This little book, comprising a series of articles, each dealing with one of the problems of refining, which originally appeared in *Chemical and Metallurgical Engineering*, is almost entirely a record of the author's personal experience.

Davison's Silk Trade.
Twenty-sixth annual edition, 1921. Pocket edition. N. Y., Davison Publishing Co. 776 pp., 8 x 5 in., cloth. $4.00.

The directory of silk mills is arranged both geographically and by products, dyers and finishers geographically, the dealers by commodities. An index of mills is included. Full information as to the size of mills, their products, officers, etc., is included.

Davison's Textile "Blue Book," United States and Canada.
Thirty-third annual edition, July, 1920 to July, 1921. Office edition. N. Y., Davison Publishing Co. 1748 pp., maps, 9 x 7 in., cloth, $7.50.

This directory covers the entire textile industry. The mills of the country are listed geographically under their products, and their sizes, officers and products noted. Commission merchants, dealers in raw and semi-finished materials, rags, waste, etc., are also included, and also a directory of dealers in textile mill supplies.

The Dynamics of the Airplane.
By Kenneth P. Williams. N. Y., John Wiley & Sons Inc.; Lond., Chapman & Hall, Ltd., 1921. (Mathematical monographs, 21.) 138 pp., diagrams, 9 x 6 in., cloth, $2.50.

Contents: The plane and cambered surface.—Straight horizontal flight.—Descent and ascent.—Circular flight.—The propeller. Performance.—Stability and controllability.
This book, intended for students of mathematics and physics who are attracted by the dynamical aspect of aviation, grew out of a course of lectures on aerodynamics given by Professor Marchis, at the University of Paris in 1919. The treatment is elementary for the most part.

E. I. Du Pont de Nemours and Company; a history 1802-1902
By B. G. du Pont. Bost. and N. Y., Houghton Miflllin Co. 1920. 196 pp., port., plates, facsims., 8 x 6 in., cloth, $3.00.

A brief general account of the growth and achievements of this company from its foundation by E. T. du Pont de Nemours, to its purchase and reorganization by T. Coleman du Pont and his associates.

Electric Welding.
By Ethan Viall. First edition. N. Y., and Lond., McGraw-Hill Book Co., Inc., 1921. 417 pp., illus., 9 x 6 in., cloth, $4.00.

Contents: Electric welding—historical.—Arc welding equipment.—Different makes of arc welding sets.—Training arc welders.—Carbon-electrode arc welding and cutting.—Arc welding procedure.—Arc welding terms and symbols.—Examples of arc-welding jobs.—Physical properties of arc-fused steel. Metallography of arc-fused steel.—Automatic arc welding.—Butt-welding machines and work.—Spot-welding machines and work.—Welding boiler tubes by the electric resistance process.—Electric welding of high-speed steel and stellite in tool manufacture.—Electric seam welding.—Making proper rates for electric welding, and the strength of welds.
This volume is a compilation of the available literature on electric welding, selected and arranged by an experienced editor. It forms a convenient source of information on present methods, apparatus and applications.

Electrical Machinery
By Ottomar H. Henschel. Chicago, Power Plant Engineering, (cop. 1920). 312 pp., illus., 8 x 5 in., cloth, $2.00.

This volume is an elementary statement of the generally accepted theories of the principles of electric machinery, presented with the aid of only elementary mathematics. Direct and alternating-current generators and motors, transformers, voltage regulators and synchronous converters are considered. The book is based upon a series of articles, entitled "A study of dynamo electric machinery," which appeared in *Power Plant Engineering*.

Elementary Machine Shop Practise.
By James A. Pratt. N. Y., D. Van Nostrand Co., 1921. 320 pp., illus., 8 x 5 in., cloth, $2.50.

This manual describes the fundamentals of the trade, the processes relating to the bench, lathe, drill press, shaper, slotter, grinder, miller and planer. The treatment is clear, detailed and non-mathematical. Suited for use by apprentices, trade school students and young workmen.

Elements of Fuel Oil and Steam Engineering.
By Robert Sibley and C. H. Delany. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 466 pp., illus., tables, 9 x 6 in., cloth, $5.00.

The theme of this book is a study of fuel-oil power-plant operation and the use of evaporative tests to increase their efficiency. It includes an exposition of the elementary laws of steam engineering, the use of oil for fuel in the modern power plant, and the testing of oil-fired boilers. This edition has been rewritten, and much new material added.

Employee Training.
By John Van Liew Morris. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 311 pp., 8 x 6 in., cloth. $3.00.

This work presents the results of an inquiry into the programs and organization machinery being utilized by various manufacturing concerns to train their own workers, both by apprenticeship courses and by vocational training. It shows industry's own solution of its training problems and should be suggestive to manufacturers as a collection of tried methods.

Hendrick's Commercial Register of the United States.
29th annual edition (1921).

N. Y., S. E. Hendricks Co., Inc., 2572 pp., 10 x 8 in., cloth, $12.50.

This well-known classified directory of manufacturers and dealers in supplies used by engineering firms has been carefully revised, new firms have been added, and those no longer extant have been eliminated. As in previous issues, the directory includes a classified list of dealers, an alphabetical list, an index of trade names, and an index of commodities.

Installing Management in Woodworking Plants.
By Carle M. Bigelow. N. Y., The Engineering Magazine Co., 1920. 323 pp., illus., 9 x 6 in., cloth, $5.00. (Gift of Industrial Management.)

Contents: Traditional peculiarities of woodworking making scientific management essential.—Organization and its installation.—Product.—Lumber.—Purchasing and storing.—Planning department.—Layout and routing of the plant.—Shop practise and standardization.—The cutting of lumber—Labor control.—Tool and fixture control.—Repair control.—Waste Control.—Power plant.—Cost accounting.—Results to be expected by application of methods outlined.
The author's purpose has been two-fold; first, to express in a general way his ideas as to the application of the principles of scientific management to an industry, and second, to outline in detail their application to the specific problems of the woodworking industry.

Kinematics and Kinetics of Machinery; a Text-Book for Colleges and Technical Schools.
By John A. Dent and Arthur C. Harper. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 383 pp., illus., tables, 9 x 6 in., cloth, $3.50.

Contents: Machine Motions, Pairs, Links, Chains, Mechanisms.—Motion of Rigid Bodies.—Velocities of Mechanisms.—Accelerations in Mechanisms.—Inertia Forces of Machine Parts.—Balancing of Engines.—Governors.—The Mechanics of the Gyroscope.—Critical Speeds and Vibrations.—Toothed Wheels.—Cams.—Wrapping Connectors.—Irregular Gears.—Propositions on Velocity Polyglons.—Locus of the Center of Acceleration.—Solution of Linear Differential Equations.—Investigation of Forces in Gasoline Engine.
This treatise gives systematic methods, mainly graphical, of determining velocities, accelerations and inertia forces which can be applied to practically all mechanisms. The text is based upon notes prepared by professors G. A. Goodenough and F. B. Seeley, and used for instruction at the University of Illinois, which have been revised and extended by the authors.

THE MANUFACTURE OF PULP AND PAPER. Vol. 1. Arithmetic, Elementary applied mathematics. How to read drawings. Elements of Physics.

By J. J. Clark. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 132 pp., illus., 9 x 6 in., cloth, $5.00.

This book is the first of a series of five volumes prepared under the auspices of the Canadian Pulp and Paper Association and the Technical Association of the Pulp and Paper Industry, which is intended to form a suitable course of study in the fundamentals of mathematics and science and the manufacturing operations involved in modern pulp and paper practise. The treatment is simple, as the books are intended for self-instruction, as well as for class room use.

MARINE ENGINEERING.

By A. E. Tompkins. Fifth edition, revised. Lond., Macmillan and Co., Ltd., 1921. 888 pp., illus., 9 x 6 in., cloth. $11.25. (Gift of the Macmillan Co., N. Y.)

An extensive one-volume text-book covering a sound course in marine engineering, treating all the subjects usually included in that term. This edition has been extensively revised and many chapters have been rewritten. Much obsolete matter has been omitted and mercantile practise has been considered more fully than before.

MODERN MARINE ENGINEERING. Part 1. The Fire Room.

By Harry G. Cisin. N. Y., D. Van Nostrand Co., 1921. 205 pp., illus., tables, 8 x 5 in., cloth. $3.00.

The purpose of the text-book of which this is a first volume, is to set forth present practise in marine engineering in a form suitable as a college text or for use by practical men preparing for engineers' licenses. This volume discusses marine boiler construction, auxiliaries, corrosion, fuels and combustion. It is based on the course given by the U. S. Navy Steam Engineering School at the Stevens Institute, during the war.

THE NEW PHYSICS.

By Albert C. Crehore. San Francisco, *Journal of Electricity*, 1920. 111 pp., 6 x 5 in., cloth.

This little book presents some results of the author's study of the fundamental conceptions and laws of physics. It gives new expressions for Rydberg's and Planck's constants, which connect them in various ways with the electrical charge and the mass of the hydrogen atom, a reduction of the electrostatic and electromagnetic systems of the units to one common system in terms of length and time, and the author's theory of the atom.

PLANE ALGEBRAIC CURVES.

By Harold Hilton. Oxford, Clarendon Press, 1920. 388 pp., diagrams, 9 x 6 in., cloth, $12.60. (Gift of the American Branch of the Oxford University Press.)

Though the theory of plane algebraic curves still attracts mathematical students, the English reader has not many suitable books at his disposal. Salmon's classic treatise was last published some forty years ago and has long been out of print. Mr. Hilton has therefore thought a new book desirable, if only to bring more recent developments within reach of the student. His book, while based on previous texts, has been largely extracted from mathematical periodicals, supplemented by his own studies, and attempts to be reasonably complete.

PRINCIPLES OF ELECTRICAL DESIGN, D-C. AND A-C. GENERATORS.

By Alfred Still. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 365 pp., diagrams, 9 x 6 in., cloth. $3.50.

This book is intended for students of electrical engineering and for this reason emphasis is laid on fundamentals and principles of general application, while little attention is given to the need of the practical designer for empirical formulas and short cuts. The author's object has been to supply a reference text to accompany a course in practical designing, which would base all arguments on scientific facts and build up designs in a logical manner from known fundamental principles, and thus assist in a thorough understanding of the essentials.

The revision covers many minor alterations and corrections and a few new methods of calculation.

THE PRINCIPLES OF THE PHASE THEORY.

By Douglas A. Clibbens. Lond., Macmillan and Co., Ltd., 1920. 383 pp., diagrams, 9 x 6 in., cloth. $10.00. (Gift of The Macmillan Co., N. Y.)

As the author believes that a thorough study of the condensed system offers the easiest path to a true understanding of the methods of the phase theory, he has given a general title to his book, which in reality is limited to the consideration of condensed systems which include only one liquid phase, and that the only phase of variable composition. The book is written primarily for readers unfamiliar with the subject.

SCREW THREAD PRODUCTION TO CLOSE LIMITS.

By Howard E. Adt. First edition. N. Y., The Stirling Press, 1920. 192 pp., illus., tables, 9 x 6 in., cloth. (Gift of the Geometric Tool Co., New Haven.)

The volume is intended primarily to direct attention to the screw cutting tools and machines manufactured by the Geometric Tool Co. It contains much general information of a practical character on screw thread standards, gaging, methods of threading, cutting speeds, lubricants, and similar subjects of general application, and includes the necessary tables, so that it will be useful to machinists as a reference book.

STUDIES IN FRENCH FORESTRY.

By Theodore S. Woolsey, Jr. With two chapters by W. B. Greeley. N. Y., John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1920. 550 pp., illus., tables, 9 x 6 in., cloth, $6.00.

Contents: Impressions of French forestry.—The role of forest.—Forest regions and important species.—Forest statistical data.—Natural regeneration.—Artificial reforestration.—Control of erosion in the mountains.—Forestry in the Landes.—Government regulation and working plans.—Features of French national forest administration.—Private forestry in France.—The American forest engineers in France.

This book is a study of the theory and practise of French forest administration and management, based upon extended trips through French forests, and an examination of the standard authorities. It supplements the author's previous volume "French Forests and Forestry," which describes the forests and forestry of Algeria, Tunisia and Corsica.

TECHNICAL METHODS OF ANALYSIS, AS EMPLOYED IN THE LABORATORIES OF ARTHUR D. LITTLE, INC., CAMBRIDGE, MASS.

Edited by Roger Castle Griffin. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. (International chemical series.) 666 pp., illus., tables, 8 x 6 in., cloth, $5.00.

This is an extensive handbook for the analytical chemist, based on the experience of a large commercial laboratory, in which most of the methods given have been used many times. Standard procedures adopted by bodies of chemists have also been included.

The book is intended to include the methods commonly needed in general commercial work, but material on drugs, alkaloids, medicines, rare earths, rocks, glasses and other substances has been excluded. The chief materials discussed are the important organic compounds, metals, fuels, paints, oils, fats, soaps, wood, paper, textiles and foodstuffs. Brief descriptions of the normal properties are frequently given. Bibliography, pp. 627-633.

A TEXT-BOOK OF ELECTRICAL ENGINEERING.

By Adolf Thomalen, translated by G. W. O. Howe. Fifth edition, Lond., Edward Arnold, 1920. 482 pp., diagrams, 9 x 6 in., cloth, $9.00. (Gift of Longmans, Green and Co.)

This book is designed to bridge the gap between elementary text-books and the specialized works on various branches of electrical engineering. It is concerned almost exclusively with principles and does not enter into details of the practical construction of apparatus and machines. It is intended to lay a thorough foundation for the profitable study of books on the design of dynamo machinery.

The present edition has been revised, extended and partly rewritten.

A TEXT-BOOK OF ORGANIC CHEMISTRY.

By A. F. Holleman. Edited by A. J. Walker, assisted by O. E. Mott. Fifth English edition, completely revised. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall Ltd., 1920. 642 pp., illus., 9 x 6 in., cloth, $3.50.

Most of the short text-books of organic chemistry, according to this author, contain a great number of isolated facts and describe so considerable a number of compounds that the beginner is confused. Moreover, the theoretical grounds are often kept in the background. In this book he has endeavored to keep the number of unconnected facts within narrow limits and to give prominence to the underlying theory.

The present edition has been carefully revised and partly rewritten.

A TEXT-BOOK OF PHYSICS.

By W. Watson. Seventh edition, revised by Herbert Moss, Lond., and N. Y., Longmans, Green & Co., 1921. 976 pp., illus., diagrams, 8 x 5 in., cloth, $6.00.

Since the publication of the sixth edition, this text-book has undergone considerable revision, during which those sections dealing with subjects in which important recent work has been done, have been revised and extended.

The book is intended for students of college grade, already familiar with the elements of the subject, who desire a more extended discussion.

TRADE TESTS: THE SCIENTIFIC MEASUREMENT OF TRADE PROFICIENCY.

By J. Crosby Chapman, with the assistance of D. R. Chapman, N. Y., Henry Holt and Co., 1921. 435 pp., illus., 9 x 6 in., cloth, $4.00.

During the war, the War Department undertook extensive researches in the effort to solve the problem of placing its skilled workers. One important result of the experimentation was the trade test, devised to enable a trained examiner, unskilled in any trade, to measure the trade standing of a person claiming skill in any of the trades necessary to the army.

The present volume sets forth some of the results obtained. Samples of oral picture, performance and written trade tests for various trades are shown, with comment on their use. The place of such tests in industry is discussed.

A TREATISE ON AIRSCREWS.

By Whyrill E. Park. N. Y., E. P. Dutton & Co., 1921. (The Directly-Useful Technical Series.) 308 pp., illus., diagrams, charts, tables, 9 x 6 in., cloth, $8.00.

This book considers the problems of airscrew propeller design and construction from the viewpoint of designers, draftsmen and others engaged in the practical design of aircraft. In general, it follows the methods developed by Lang Propeller, Ltd. It is intended to supply directly useful information, accompanied by a proper amount of scientific explanation. The theory presented is one that has proved convenient for drafting-room use.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—March 23, 1921. Subject: "The Panama Canal and its Electrification." Speaker: Mr. D. C. Hooper. Mr. Henton, a visitor, also gave a talk on gold metallurgy, making particular reference to the Black Hill Section in South Dakota. Attendance 16.

Boston.—March 15, 1921, Engineers Club. Paper: "High Lights of Air Travel." Author: Mr. M. Luckiesh, Director of Applied Science, Nela Research Laboratory, Clevel nd, O. The paper dealt with the beauties, wonders and possibilities of airplane flights. Attendance 94.

Cleveland.—March 14, 1921. Cleveland Social Club Rooms. Joint meeting with the Association of Iron and Steel Electrical Engineers. Paper: "Electric Propulsion of Ships." (by Mr. W. E. Thow.) Speaker: Mr. Ralph Kelley, who has worked with the author in this field. Attendance 120.

Denver.—March 19, 1921, Kenmark Hotel. Subject: "Valuation and Rate Making Concerning Utilities." Speakers: Messrs. G. H. Throop and H. A. Belden, Valuation Engineers for the J. G. White Engineering Corporation of New York. Attendance 50.

Fort Wayne.—March 24, 1921, General Electric Club Rooms. Subject: "Modern Transformer Practise." Speaker: Mr. E. A. Wagner. Mr. Wagner discussed the development and construction of several different types of transformers which are built at Fort Wayne, and slides were shown illustrating the details of construction. Attendance 27.

Kansas City.—March 25, 1921, Northeast Power House of Kansas City Light and Power Company. Subject: "Construction of the Northeast Power House." Speaker: Mr. H. C. Blackwell, General Manager, Kansas City Light & Power Company. Mr. R. Frisbie also discussed the Generator and Station Protection as installed at the Northeast Power House. Attendance 56.

Los Angeles.—March 22, 1921, Edison Hall. Subject: "Our Debt to the Pioneers of Science." Speaker: Mr. Samuel G. McMeen. Entertainment, movies and music followed. Attendance 130.

Lynn.—March 19, 1921, City Club, Boston. Tenth Annual Banquet of the Section. After the banquet two films were shown, one of the operation of X-Ray Apparatus and the other on the application of electricity to logging operations and lumber mills. General T. C. Dickson, Commandant of the Watertown Arsenal, gave a very interesting lecture on the labor situation during the war and how it was handled by the Government; followed by Professor Arthur Gordon Webster, of Clark University, who in a humorous way told how to get rich. Other speakers were Professor Elihu Thomson, Richard H. Rice and F. P. Cox. Attendance 390.

April 6, 1921, Classical High School, Lynn. Ladies' Night. Mr. John B. Taylor, of the General Electric Company, Schenectady, gave a very interesting lecture on "Instruments of the Orchestra," explaining why and how sounds are produced on various orchestral instruments and the value to the orchestra as a whole. The lecture was preceded by a concert given by two soloists and a large orchestra, all of whom were employees of the General Electric Company. Attendance 750.

Minnesota.—February 28, 1921, Auditorium, University of Minnesota. Subject: "Radio Telephone." Speaker: Professor C. M. Jansky, Jr. of the University of Minnesota. Prof. Jansky gave a very interesting history of the development of the Radio Telephone and a description of the apparatus used in the early experimental stages and the development of this apparatus to that used today. He demonstrated these various pieces of apparatus and diagrams of circuits on the blackboard. Attendance 120.

Omaha.—March 21, 1921, University Club. Organization meeting. Temporary officers: Chairman, Mr. H. C. Evarts; Secreatry, Mr. L. E. Rudolph. Attendance 10.

Philadelphia.—March 22, 1921, Witherspoon Hall. Subject: "How the Engineer Can Best Capitalize Himself." Speaker: Mr. Richard Spillane. Joint meeting with affiliated societies of the Engineers' Club of Philadelphia and the Engineers' club. Attendance 925.

April 11, 1921, Engineers' Club of Philadelphia. Subject: "Niagara Falls Power and the Reason for its Development." Speaker: Mr. John L. Harper, Vice-President and Chief Engineer of Niagara Falls Power Company. Attendance 83.

Pittsfield.—March 17, 1921, Boys' Club. Subject: "Wireless Telephony." Speaker: Dr. B. F. Jewett, Chief Engineer, Western Electric Company. Attendance 250.

March 31, 1921, Park Club. Subject: "Airplane Flight." Speaker: Dr. Frederick Bedell, Cornell University. Attendance 135.

Providence.—March 15, 1921, Providence Engineering Society Rooms. Joint meeting with Providence Engineering Society. Subject: "Electrification of Steam Railroads." Speaker: Mr. C. C. Whittaker, of the Westinghouse Elec. & Mfg. Co., E. Pittsburgh. The talk was illustrated with lantern slides. Attendance 60.

April 1, 1921, Engineering Society Rooms. Joint meeting with the Telephone Society of Rhode Island. Subject: "The Practical Application of Telephone Repeaters." Speaker: Mr. H. S. Osborne, Transmission Engineer of the A. T. & T. Co. The talk was illustrated with lantern slides. Attendance 50.

Rochester.—March 25, 1921, Subject: "Einstein Theory of Relativity." Speaker: Dr. Arthur S. Gale, Professor of Mathematics of the University of Rochester. The speaker summarized the historical development of the theory of relativity, describing the classic experiment of Michelson undertaken to determine the absolute velocity of the earth through the ether by means of the interferometer. A simple form of Einstein Theory was stated with numerous illustrations, the speaker concluding by passing to a general discussion of relativity. Attendance 51.

St. Louis.—March 23, 1921, Engineers' Club. Subject: "Power Situation in St. Louis District." Speaker: Mr. L. H. Egan, President, Union Electric Light & Power Company. Attendance 135.

San Francisco.—February 25, 1921, Engineers' Club. Subject: "Practical Talk on Modern Methods of Radio Communication." Speaker: Captain C. I. Hoppough, Signal Corps, U. S. A. Attendance 104.

Schenectady.—March 18, 1921, Edison Club Hall. Subject: "Hot Cathode Devices: Their Principles and Applications." Speaker: Dr. Saul Dushman, of the Research Laboratory of the General Electric Company, Schenectady. Attendance 200.

April 1, 1921, Edison Club Hall. Subject: "The Elements of Einstein's Theory." Speaker: Professor C. L. E. Moore, of Massachusetts Institute of Technology. Attendance 260.

Seattle.—March 15, 1921. Mr. C. F. Uhden, Engineer in Charge of the Skagit River Power Project, showed a large number of very interesting lantern slides showing the nature of the upper Skagit River Valley and some of the construction work already completed. He also gave in a concise way the general features of the ultimate project and explained what the first installation would include. Attendance 85.

Spokane.—February 21, 1921, Davenport Hotel. Joint meeting with the Associated Engineers. Subject: "The Engineer and His Opportunity." Speaker: Mr. E. S. Carman, President, A. S. M. E. Attendance 37.

March 18, 1921, Davenport Hotel. Joint meeting with Associated Engineers. A four reel motion picture entitled "The Story of Petroleum." was shown. Attendance 74.

Toronto.—March 18, 1921, Toronto University. Subject: "Switching Equipment." Speaker: Mr. L. B. Chubbuck, of the Canadian Westinghouse Company. Mr. Chubbuck had collected a large number of slides illustrating switching connections and apparatus in the power houses of the Niagara Falls Power Company, the Shawinigan developments, the Hydro-Electric Power Commission of Ontario, the Ontario Power Company, and other plants. After the slides, the films which were recently presented at the Midwinter Convention of the Institute were shown, illustrating the operation of circuit breakers and fuses under abnormal overload conditions. Attendance 135.

April 1, 1921, Toronto University. Joint meeting with Ontario Section A. S. M. E. and Toronto Chapter A. S. S. T. Subject: "The Manufacture of Armco Ingot Iron and Special Steel Sheets," illustrated with motion pictures. Speaker: Mr. T. W. Jenkins, American Rolling Mills Company. Attendance 150.

April 8, 1921, Toronto University. Subject: "The Application of Acoustic Engineering to Fog Alarm Problems," illustrated. Speaker: Professor Louis V. King, McGill University. Attendance 57.

Urbana.—March 18, 1921. Subject: "The Fatigue or Progressive Failure of Metals." Speaker: Professor H. F. Moore. Attendance 82.

Vancouver.—March 21, 1921. Joint meeting with the British Columbia Technical Association. Subject: "Electric Energy Rates." Speaker: Mr. E. E. Walker, Sales Manager of the B. C. Electric Railway Co. Ltd. Attendance 36.

March 31, 1921. Subject: "1200-Volt B. C. Electric Railway Equipment." Speaker: Mr. R. L. Hall, E. E., B. C. Electric Railway Company. The paper was well illustrated with lantern slides, curves, calculations data, diagrams, etc. Attendance 26.

Worcester.—March 29, 1921. Subject: "Operation of the New England Power Company System." Speaker: Mr. A. S. Walker, Chief Load Dispatcher for new England Power Company. Mr. Walker described the development and equipment of the New England Power Company and the methods used in determining stream flow and in dispatching power load in accordance therewith. Attendance 80.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—March 3, 1921. Subject: "The Engineer Salesman." Speaker: Mr. E. F. Pearce, of the Atlanta Office of the General Electric Company. Attendance 33.

March 31, 1921. Subject: "Electric Railways." Speaker: Mr. E. F. Sanborn. Attendance 45.

University of Arkansas.—March 15, 1921. Election of officers for spring quarter as follows: Chairman, S. E. Hollabaugh, Jr.; Vice-Chairman, Maximilliam X. Ware; Secretary, L. Gale Huggins; Treasurer, Archie Blackburn. Subjects: "A National Survey of Waste" by R. J. Horn; "Some Electrical Causes of Dust Explosions" by Jack Thompson; "Future Power Development" by R. P. Hart. Attendance 10.

Armour Institute of Technology.—April 7, 1921. Subject: "Substation Design." Speaker: Professor John A. Snow. Attendance 32.

Bucknell University.—March 16, 1921. Moving picture of the Westinghouse Company, entitled "That Little Snowflake" was shown. Attendance 125.

University of California.—March 9, 1921. Paper: "Theory and Workings of the Magnavox or Electro-Dynamic Receiver." Author: Mr. Herbert Metcalf, Magnavox Company of San Francisco. Attendance 61.

April 6, 1921. Subject: "Commercial Phases of Electric Drive." Speaker: Mr. M. Rhine, General Electric Company. Attendance 32.

University of Cincinnati.—February 8, 1921. Subject: "Flying." Speaker: Mr. H. H. Bush. Attendance 126.

February 15, 1921. Subject: "A-C. Motor Control." Speaker: Mr. E. B. Smith, General Electric Company. Attendance 40.

March 8, 1921. Subject: "A New Method for Accurate Alignment of Bearings." Speaker: Mr. T. R. Watts. Attendance 40.

March 15, 1921. Subject: "The Results of an Electrolysis Survey in West Virginia during the Summer of 1920." Attendance 65.

March 22, 1921. Subject: "Graphic Meters and What They Tell." Speaker: Mr. J. Esterline, President of the Esterline Company. Attendance 107.

March 29, 1921. Subject: "Electric Metering and Meter Departments of Central Stations." Speaker: Mr. G. C. Brown. Attendance 49.

April 5, 1921. Subject: "Electricity and Civilization." Speaker: Professor A. M. Wilson. Attendance 69.

April 12, 1921. Subject: "The Power Plant of a Paper Mill." Speaker: Mr. H. E. Hennegerin. Attendance 77.

Clarkson College of Technology.—March 15, 1921. Election of officers as follows: Chairman, M. Johnston; Secretary, L. H. Cline; Treasurer, R. W. Tozer. Attendance 23.

Clemson Agricultural College.—March 24, 1921. Subject: "George Westinghouse." Speaker: Mr. W. E. Freeman. Attendance 57.

University of Colorado.—March 24, 1921. Subject: "Electric Arc Welding," illustrated. Speaker: Mr. G. N. Robinson, of the Denver Branch of the General Electric Company. Attendance 82.

Iowa State College.—March 16, 1921. Election of officers as follows: Chairman, A. S. Egulf; Vice-Chairman, A. H. Eschbach; Secretary, A. F. Kenyon; Treasurer, C. A. Molsberry. Subject: "Electric Distribution System of the Denver Gas & Electric Company." Speaker: Professor Frank D. Paine. Attendance 51.

April 6, 1921. Joint meeting of Branches of A. I. E. E. and A. S. M. E. Subject: "The Foundry, Its Design, Construction, and Equipment for Efficient Operation." Speaker: Mr. Ferguson, of the Frank Chase Co., Inc., Engineers. Attendance 32.

University of Iowa.—March 8, 1921. Subjects: "Super Chargers for Aeroplanes" by T. Roche; "The New Brunswick Radio Station" by Allen Rockwood; "The Steinmetz Electrical Vehicle" by Charles Krause. Attendance 29.

March 21, 1921. Subject: "Railroad Electrification." Speaker: Mr. R. Owen. Attendance 22.

Kansas State Agricultural College.—March 10, 1921. Subjects: "A. I. E. E. Membership and its Advantages" by Professor Reed; "Advertisements" by Mr. E. Doming; "Radio Telephony" by Mr. G. W. Glendening. Attendance 83.

University of Kansas.—March 17, 1921. Subject: "Historical and Modern Phases of Architecture." Speaker: Professor Goldsmith. Attendance 25.

Lehigh University.—March 10, 1921. Subject: "The Superpower System, Its Answer to a National Power Policy." Speaker: Mr. William S. Murray. Attendance 289.

University of Maine.—March 10, 1921. Mr. R. M. Jocylen gave an illustrated lecture on the Panama Canal. Professor A. S. Hill talked on the Foundations which determine the future of the young engineer. Attendance 28.

Massachusetts Institute of Technology.—March 24, 1921. Subject: "Magnets and Coils," illustrated. Speaker: Mr. C. R. Underhill, of the Acme Wire Co., New Haven, Conn. Smokes and refreshments were served. Attendance 85.

Michigan Agricultural College.—March 16, 1921. Election of officers as follows: Chairman, H. L. Fleming; Secretary-Treasurer, C. M. Brown. Subject: "Report on the New York A. I. E. E. Convention Held February 16-18, 1921." Speaker: Professor M. Cory. Attendance 35.

April 12, 1921. Moving picture entitled "The Electric Giant" was shown. Professor Cory gave an interesting talk on "The Design of Turbo-Generators." Attendance 33.

University of Michigan.—March 23, 1921. Subject: "Some Applications of Electricity to Industrial Heating." Speaker: Mr. J. S. Gault. A reel of motion pictures on the construction of a 150,000 h. p. turbo-alternator was shown. Attendance 23.

April 5, 1921. Subject: "Interesting Experiences in the Application of Heavy Duty Motors." Speaker: Mr. Harry J. Fisher, of the Reliance Motor Company of Cleveland. Attendance 34.

University of North Carolina.—February 11, 1921. Subjects: "Individual Motor Drive in Print Shops," by Mr. T. Larsen; "Central Station Operation," by Mr. C. G. Mauney; "Polarity in Transformers," by Mr. M. E. Lake; "Time Limit Cutouts," by Mr. P. C. Smith. Attendance 38.

February 25, 1921. Subjects: "Construction of Transmission Lines" by Mr. G. Brown; "Controllers" by Mr. B. E. Humphrey; "Electric Ship Propulsion" by Mr. R. A. Tillman; "By-Product Coke" by Mr. C. J. Bryan. Attendance 47.

Ohio Northern University.—March 17, 1921. Subjects: "The Vacuum Tube" by Mr. L. A. Kille; "Tidal Power" by Mr. Elmer Stoker; "Remarks" by Mr. Morris Elder. Attendance 26.

April 7, 1921. Subject: "Applications of Electricity in Coal Mines." Speaker: Mr. B. L. Decker. Attendance 11.

Ohio State University.—March 11, 1921. Business meeting, followed by a talk by Professor W. A. Knight on his early electrical experiences in Columbus. Attendance 40.

April 1, 1921. Election of officers as follows: Chairman, J. O. Sherrard; Vice-Chairman, E. K. Clark; Financial Secretary, L. D. Barley; Junior Representative, R. L. Brown; Sophmore Representative, J. Fies. Subject: "Describing the Structural and Electrical Features of the new Telegraph Office of the Western Union Company at Chicago." Speaker: Mr. P. J. Howe, of the Western Union Company. Attendance 37.

Oregon State Agricultural College.—March 9, 1921. Two reels of moving pictures entitled "Big Deeds and Revelations" were shown. Attendance 35.

Pennsylvania State College.—March 10, 1921. Subject: "Shunt and Series Relays." Speaker: Mr. Woodruff. The paper of the A. E. S. C. on "National and International Standardization" was read before the Branch. Attendance 43.

University of Pennsylvania.—March 4, 1921. Subject: "Pyrometers and Their Application." Speaker: Mr. C. H. White. Attendance 41.

March 11, 1921. Subject: "Three-Electrode Vacuum Tube." Speaker: Mr. J. Mauran. Attendance 41.

University of Pittsburgh.—March 15, 1921. Subjects: "Fire Control of 12-inch Mortars" by Mr. P. O. Langgath; "Watt-Hour Meters" by Mr. J. W. Hirsch; "The Manufacture of Bakelite" by Mr. K. Appasamy. Attendance 27.

April 5, 1921. Subject: "The West Penn Power Plant at Springdale." Speaker: Mr. L. L. Pendleton. Attendance 30.

Rose Polytechnic Institute.—March 10, 1921. Subject: "Electric Furnaces." Speaker: Mr. H. A. Schwartz, of the National Malleable Castings Company. Attendance 113.

April 1, 1921. Subject: "Development of Electrical Power in Indiana Coal Fields." Speaker: Mr. J. W. Dunbar. Attendance 23.

Syracuse University.—March 4, 1921. Subject: "Automatic Telephones." Speaker: Mr. Barnes. Attendance 13.

April 1, 1921. Moving picture entitled "Romance of the Rails" was shown. Attendance 23.

April 8, 1921. Subject: "H. L. Grid Controllers." Speaker: Mr. L. M. Moore. Attendance 13.

Texas A. & M. College.—March 22, 1921. Subjects: "Recent Developments in Electrification of Battleships" by Mr. R. B. Steele; "The Whys of Railroad Electrification" by Mr. E. L. Robinson. Attendance 36.

University of Texas.—March 28, 1921. Subjects: "Fundamentals of Wireless" by Mr. J. P. Buchanan; "Spark and Continuous Wave Sets" by Mr. George Endress; "Vacuum Tubes" by Mr. George Reeves; "Wireless Communication" by Mr. C. Read Granberry; "The Talking Arc" by Mr. J. P. Buchanan. Demonstrations of apparatus. Attendance 150.

Virginia Military Institute.—March 19, 1921. Subjects: "What is Power Factor" by Mr. Blackwell; "The Induction Motor" by Mr. Harwood. Interesting comment by Col. Stewart W. Anderson on the use of the Synchronous Motor. Attendance 90.

Virginia Polytechnic Institute.—February 28, 1921. Subjects: "The Evolution of the Transformer" by Mr. W. O. Wirt; "The Early Development and Construction of the Telephone" by Professor Lee, illustrated by a set of his personal slides on the subject. Attendance 34.

March 28, 1921. Mr. W. E. Freeman, Supervisor of Commercial Training of the Educational Department, Westinghouse Elec. & Mfg. Co., gave a very interesting talk on the life and works of Mr. George Westinghouse and the advantages offered by the Westinghouse Company to the technical graduate. Attendance 59.

Washington University.—March 24, 1921. Subject: "Transmission Problems in Long Distance Telephony." Speaker: Mr. C. F. Craig, District Plant Superintendent of the St. Louis Branch of the A. T. & T. Co. Attendance 12.

State College of Washington.—March 18, 1921. Moving pictures were shown on the Hawaiian Sugar Industry and Making of Rubber Tires. Attendance 18.

University of Washington.—March 8, 1921. Subject: "Sales Engineering." Speaker: Mr. J. Clint McDougal. Attendance 24.

West Virginia University.—March 28, 1921. Subjects: "The Pointolite Lamp" by Mr. R. B. Walker; "The Electron Theory" by Mr. J. L. Hark; "Oxide Film Lightning Arresters" by Mr. A. E. LaPoe; "The New Bridge at Fairmont" by Mr. R. D. Brown. Attendance 15.

April 11, 1921.—Subjects: "Automobile Ignition Systems" by Mr. W. D. Stump; "Sterilizing by Ultra Violet Rays" by Mr. R. M. Hanks; "Limitations of High-Voltage Transmission" by Mr. R. L. Sheffer. Attendance 15.

Yale University.—April 14, 1921. Subject: "Steel Towers for Power Transmission Circuits." Speaker: Mr. W. K. Archbold, President of the Archbold-Brady Co., Syracuse. Attendance 44.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

SERVICES AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

RECENT TECHNICAL GRADUATE with some practical experience, preferably industrial, wanted for general instruction work in a correspondence school. Teaching experience desirable but not essential. Some engineering experience, either before or after graduation, is essential, also the ability to handle correspondence. Location New York City. X-304.

ELECTRICAL ENGINEER. An electrical engineer graduate of a high grade technical school with a year of subsequent experience in testing. The work will require a man who understands the theory and design of a-c. motors, of sizes up to 100 h. p., and who can work up the data obtained from shop tests of such motors. Location New York. X-317.

COMBUSTION ENGINEER with fuel oil experience. Location Cuba. Spanish essential. X-311.

ELECTRICAL OR MECHANICAL ENGINEER, technical graduate with two or three years practical experience in power station, substation, transmission and distribution work. The work to consist largely in analyzing construction and operation costs, preparation of contracts and estimates for future work and the preparation of special reports. Give detail of experience, references and salary expected in the first letter. Location New York City. X-316.

DRAFTSMEN (10) electrical graduates. Must be very good letterers, and be experienced in design of power house equipment, substation design and equipment, high tension line design and other electrical work associated with this class of engineering. Location Pa. X-327.

CHIEF DRAFTSMAN under age of 45 years. Experienced in electrical, civil and mechanical design for power plants, steel structures and railways, to take charge of draftsmen in engineering office. Must be diplomatic and able to supervise force and get results. Location Middle West. X-340.

ASSISTANT ELECTRICAL ENGINEERS experienced in preparations of specifications for electrical equipment and construction. Also in estimating cost and calculating stresses from designs and switches for construction of sub-stations, tension lines and power stations. Location Middle West. X-341.

DESIGNING DRAFTSMEN, civil, electrical and mechanical draftsmen, under 35 years of age, good letterers and designers. Location Middle West. X-342.

SALES ENGINEER with experience in high pressure steam piping and valve layouts. Some experience necessary with small direct and alternating current motors and circuits. Location. New York City. X-343.

SALES ENGINEER acquainted with steel mill electrical and mechanical engineers, to advise on high pressure steam and water piping and gate valve layouts. Should have some knowledge of direct and alternating current small motors and circuits. Location New York City. X-344.

SALES ENGINEERS with demonstrated selling ability to sell Elevator Guide Rail lubricator. Experience in building supply or power plant specialty lines desirable. Long residence in the city where they intend to work would be helpful. Men 25-35 would be most suitable. Territory open—Chicago, Philadelphia, Detroit and Cleveland. X-348.

YOUNG ENERGETIC MAN, who has had some training in operation of street railway, combined with some electric knowledge for position with superintendent who today looks after the operation of master mechanic, track foreman, overhead foreman, etc. as well as all the income from railway, advertising, etc. Superintendent is really local manager of entire property. Require individual who will step in between superintendent and various operating individuals above enumerated. The property consists of both city and interurban railway, city property about eight (8) miles in length and interurban about sixteen (16) miles, both double track properties, with necessary shop facilities, accounting, etc. Application by letter only giving age, education and salary. Location New York State. X-351.

ASPHALT ROOFING SALESMEN for foreign service. Men with broad practical experience both in selling and application work. X-352.

ENGINEERING DRAFTSMAN experienced in the design and development of globe gate and angle valves of more or less competitive type. Location Conn. X-361.

ENGINEER to do electrical testing in experimental department on small motors with either practical or technical training along these lines. Application by letter. Location Ohio. X-390.

YOUNG TECHNICAL MEN preferably recent graduates, with sales experience. The nature of the work is sale of electrical lines. Commission basis. Location—in and around New York City. X-391.

ELECTRICAL ESTIMATOR, who can figure on electric wiring. Big job. Careful man necessary; must be experienced. Position temporary. X-402.

ELECTRICAL FOREMAN for new P. S., looking after electrical operation and maintenance. Should have had considerable operating experience, also construction and some test. Should be man capable of advancing. Application by letter only. Location New York. X-408.

RECENT ELECTRIC ENGINEERING COLLEGE GRADUATE wanted for telephone development and research work in New York City. Capability of doing original work, broad technical training and acceptable personality are essential. Good opportunity for advancement. Give complete details regarding technical and personal qualifications. Application by letter only. Location New York City. X-418.

MECHANICAL DESIGNING DRAFTSMAN, thoroughly familiar and experienced in the design of large a-c. and d-c. motors. Must be capable of developing original ideas and handling squad of detailers. Only men with long experience considered. Position permanent. Give full details as to experience, age, nationality and salary expected. Location New Jersey. X-421.

ELECTRIC METER TESTERS. First class man. Location South Carolina. X-424.

GRADUATE ELECTRICAL ENGINEER who has had experience with General Electric, Westinghouse or similar companies for public utility company in Central America. Must be familiar with design, construction, and repairs of power plants and distribution systems. Commercial experience and Spanish also desirable. Should not be over 26 years old. Location Central America. X-425.

ELECTRICAL RESEARCH ENGINEER having thorough basic training with sufficient practical experience in electrical work to undertake important responsible problems. Familiarity with technique of alternating current work as applied in power and telephone fields very desirable. Should be capable as an executive. Work requires resourcefulness and initiative. Location near San Francisco. X-428.

THE UNITED STATES CIVIL SERVICE COMMISSION announces open competitive examinations for the following positions: Associate Electrical Engineer, at $3000 to $4000 a year; Junior Electrical Engineer, at $1500 to $2000 a year; to fill vacancies in the Bureau of Mines, Department of the Interior for duty at Pittsburgh, Pa., and in positions requiring similar qualifications throughout the United States. Also: Electrical Engineer, at $2400 to $3600 a year; Assistant Electrical Engineer, at $2000 to $2400 a year; Electrical Assistant, at $1500 to $2000 a year; to fill vacancies in the Signal Service at Large, Washington, D. C., and in positions requiring similar qualifications. Also: Sound Inspector, at $8 to $9.60 per diem, to fill a vacancy in the Bureau of Engineering, Navy Department, Washington, D. C., and vacancies in positions requiring similar qualifications. All of the vacancies are to be filled from the examinations, at the salaries listed, or at higher or lower salaries, unless it is found in the interest of the service to fill any vacancy by reinstatement, transfer, or promotion. Applicants should apply at once for the form desired, stating the exact title of the examination, from those listed above, to the Civil Service Commission, Washington, D. C.; the Secretary of the United States Civil Service Board, Customhouse, Boston, Mass., New York, N. Y., New Orleans, La., Honolulu, Hawaii; Post Office, Philadelphia, Pa., Atlanta, Ga., Cincinnati, O., Chicago, Ill., St. Paul, Minn., Seattle, Wash., San Francisco, Cal., Denver Col.; Old Customhouse, St. Louis, Mo.; Administration Bldg., Balboa Heights, Canal Zone; or to the Chairman of the Porto Rican Civil Service Commission, San Juan, P. R. Receipt of applications closes May 24, 1921.

MEN AVAILABLE

DRAFTSMAN ENGINEER experienced on oil well machinery; manufacture of 6 in. shells and equipment for manufacturing same; general construction in large asphalt refinery; graduate electrical engineer 1915. Accustomed to team work. Wants to connect with company affording excellent opportunity for service growth and responsibility. E-2629.

GRADUATE ELECTRICAL ENGINEER (1918). Registered patent attorney; with executive ability. Exceptional industrial training. Qualified as chief engineer and patent attorney to small manufacturing concern or assistant to chief engineer or general manager of large one. Employed at present. Available 30 days. Minimum $3500. E-2630.

YOUNG MAN, age 24; single, desires position as electrician with some desirable firm, where efforts will be considered. One year of practical construction work in electrical power devices. Now available and will consider any place in U. S. Good references. Associate A. I. E. E. E-2631.

YOUNG ELECTRICAL ENGINEER, practical; age 23; American. Not afraid to learn or work. Have you a position for me? Seven years experience on a-c. and d-c. engineering, etc. Attended School of Eng. Milwaukee. Assoc. A. I. E. E., Mem. N. A. S. E. and A. A. A. S. Prefer South or West. Available immediately. E-2632.

ELECTRICAL ENGINEERING graduate; age 25; married, with engineering laboratory, sales and executive experience, desires connection with industrial, construction, or consulting engineering firm. Available on short notice. E-2633.

GRADUATE ELECTRICAL ENGINEER with eight years construction and operating experience with public utility companies. Desires executive work such as assistant to manager of several properties. Correspondence solicited. E-2634.

ELECTRICAL ENGINEER, University graduate; Assoc. A. I. E. E., age 23. Two years experience in generation and transmission. Desires position preferably high tension transmission. Location North America or Europe. E-2635.

ELECTRICAL AND MECHANICAL ENGINEER desires responsible position with reliable company in foreign field. Technical graduate; two years broad construction experience with steel corporation, two years with public utilities; power and substation construction, estimating, valuation, and general engineering work. Familiar with transmission and distribution practise. E-2636.

ELECTRICAL ENGINEER age 36; married. Ten years General Electric Co. Test Dept; one year drafting; one year installation of steam turbine; one year electrical maintenance, five years assistant foreman and foreman of mining low assembly department General Elec. Co. Erie, Pa. Two years 1st Lieut. Engineers. E-2637.

PROFESSOR OF ELECTRICAL ENGINEER, University of Wisconsin graduate, A. B., E. E. age 34. Seven years experience in electrical construction. Three years head of electrical engineering department of western university. Desires position as professor in large middle western or western university with opportunity of developing consulting practise. Minimum salary $3500. E-2638.

ELECTRICAL ENGINEER, age 32; single. Nine months testing experience with Westinghouse Elec. & Mfg. Co., four years with large electric railway company. Experience includes electrolysis investigation, cable inspection, and solution of problem pertaining to electric traction and power plant operation. E-2639.

EXPERIENCED RESEARCH PHYSICIST. Fifteen years industrial research in Bureau of Standards and in two of largest manufacturing concerns; eight years in charge of highest grade of research. Experienced in organization and administration of research work. Salary $6000. E-2640.

ELECTRICAL ENGINEER. Four years experience with large electrical manufacturer in testing and railway engineering departments. Technical graduate. Position wanted with electric railway company where duties will concern electrical equipment of both power house and rolling stock. Available in 30 days. Salary $250. E-2641.

EX-ARMY OFFICE (Major) having had eighteen years experience in telephone engineering, cable installations, d-c. Light and Power systems; also as executive and office manager, desires to connect with manufacturer or firm. Can invest limited amount of capital in profitable business. E-2642.

MECHANICAL ENGINEER, age 31. Eight years experience in mechanical and electrical engineering work including design, construction and maintenance of hydroelectric installations; standardization of shop manufacturing methods in metal trades; purchasing; office management. Expert in electric welding. Sound business training. Desires position of responsibility; location immaterial. References all past employers. E-2643.

YOUNG ELECTRICAL ENGINEER, Associate A. I. E. E.; age 23; single. Six years experience in industrial and power plant work, desires to make connection with industrial power plant construction or general consulting concern. At present employed as engineering draftsman of large engineering corporation. Available at once. Location no object. E-2644.

INSTRUCTOR OR ASSISTANT PROFESSOR. University graduate; E. E. having some teaching experience and three years public utility experience, seeks position with educational institution next fall. Wide awake and interested young man, age 25; married. Assoc. A. I. E. E. Prefer location central or Western U. S. with institution offering satisfactory permanent position. E-2645.

ELECTRICAL ENGINEER, age 25; graduate M. I. T. desires change offering position with broader opportunities. Two years

office and field work with large power corporation. Salary $2500. Available on short notice. E-2646.

EXECUTIVE, with 12 years broad engineering experience and sound business training, desires executive position to which engineering knowledge is essential, and which has a future sufficiently attractive to warrant change. Assoc. A. I. E. E. Assoc. Mem. A. S. M. E. Age 34; married. Location immaterial. Present salary $6000. E-2647.

ENGINEER AND EXECUTIVE. Five years practical experience doing graduate work at present, desires employment during afternoons, as assistant to executive. Has specialized on industrial problems of an economic nature. E-2648.

MECHANICAL ENGINEER can sell a good product. Sales experience with adequate compensation desired. Age 30; Cornell graduate. Six years industrial plant design; seven months construction; three years in army. Special knowledge; oil industry; paper and pulp business. Available May 1st. E-2649.

TECHNICAL GRADUATE, two years Westinghouse test; two years responsible construction work with large operating company; two years superintendent of power company in city of 70,000. Varied power sales experience. Available on two months notice as manager of power sales or assistant to general manager of power company. Salary $3000. E-2650.

ERECTING ENGINEER, age 34; technical education. Ten years construction department General Electric Co. power station and electric railways installation and operation; four years supervision of electrical installations on all types cranes, car dumpers, coal, and ore bridges, and coal handling machinery. Best references furnished. Available immediately. Assoc. A. I. E. E. E-2651.

ELECTRICAL ENGINEER, technical graduate 1907. Four years railway electrification; three years on large industrial application; two years with Central Station Co., five years as electrical engineer with large street railway with which I am now employed; including four years experience with application of automatic substations. E-2652.

ELECTRICAL ENGINEER, graduate M. I. T., two and one half years experience including General Electric test, wishes position in New York City. Character and education the best. Can arrange personal interview any time. E-2653.

ELECTRICAL-MECHANICAL ENGINEER AND EXECUTIVE. Twelve years practical experience; design construction, operation power plants, industrial equipment, outside construction. University graduate, Assoc. A. I. E. E. Best of references. Excellent reason for change. Only position with room at top considered. Married. West preferred. Present salary $3900. E-2654.

GRADUATE ELECTRICAL ENGINEER, B. S. degree, with experience in wireless, motor and generator test work desires position on test work or as assistant designing engineer. Thoroughly familiar with above named work. Energetic and reliable; good references furnished. E-2655.

GRADUATE ENGINEER with 15 years experience in design, construction and combustion work with public service and private power plants also purchasing and sales experience, desires permanent position in executive work with reliable company. Age 37; married. E-2656.

ELECTRICAL MECHANICAL ENGINEER, University graduate; age 25. One year with large electric railway and light company; one year of business experience. Desires connection with sales engineering or industrial concern. Location preferred, Michigan or bordering states. E-2657.

GRADUATE ELECTRICAL ENGINEER, Member A. I. E. E. Twelve years experience in marine electrical work, and manufacturing. Former Capt. of Engineers in World War. Location in or near New York City preferred. Past five years in responsible charge of work. E-2658.

GENERAL FOREMAN AND CHIEF ELECTRICIAN. Ten years experience on construction, operation and maintenance of electrical and mechanical equipment; also thorough knowledge of gas engines. Instructor while in United States Army and Inspector for General Electric Company. Good organizer and can handle large force of men. Wishes position as head of maintenance department, chief electrician or plant foreman. Married; age 30. Salary $3000. E-2659.

ELECTRICAL MECHANICAL ENGINEER, graduate Cornell and Pennsylvania State. Seven years experience design construction, operation, management, large power developments, high tension, distribution hydraulics, thermodynamics, contracts, specifications, reports, valuation, costs, efficiency work, desires connection with future where executive and engineering ability are requisites. Best references. Salary $4800. E-2660.

ELECTRICAL ENGINEER, age 39; married; technical graduate. Fifteen years experience in transmission and distribution; hydro and steam station design and installation. For past three years with consulting engineering firm. Present salary $3000. Available in two weeks notice to present employers. E-2661.

TECHNICAL GRADUATE in industrial electrical engineering, desires position as assistant in electrical engineering department of railroad or operating company. Two years General Electric test; five years railroad operating and construction experience; one and half years in engineering department of large electrical manufacturing concern. Single; age 35; minimum salary $1800. E-2662.

TECHNICAL GRADUATE, age 22; single, desires position in electrical industry, preferably Central Station, with opportunity to learn and advance. Not afraid of work. Available about June 15th; references. E-2663.

ENGINEERING ACCOUNTANT, graduate electrical engineer, ten years experience in design, manufacture, test, theory and cost of insulated wires and cables, seeks position with manufacturing firm, consulting engineer, or firm of cost engineers. Is especially desirous of doing cost and production engineering in the above or any other line of work. E-2664.

ELECTRICAL ENGINEER, age 32; married. Sixteen years experience, correspondence graduate desires connection with future. Familiar with hydroelectric, telephone, construction, also three phase industrial maintenance. At present employed by large maining company as electrical engineer. Available sixty days. Prefer mining connection in Mexico, South or Central America. Salary $3000. E-2665.

ELECTRICAL ENGINEER, age 27; college graduate (B. S.) and technical school graduate (E. E.). Three years experience along broad engineering lines, power plants, laboratory research, electrical engineering works. Location immaterial. E-2666.

EXECUTIVE. Electrical engineer, long experience sales and export executive in wire and cables. Also broad business training including purchasing, banking credits and shipping. Available immediately. E-2667.

ENGINEERING EXECUTIVE. Graduate electrical engineer, Harvard. Captain Coast Artillery; age 34. Extensive experience in construction and operation. Desires permanent position with utility or industrial company where wide engineering experience will be valuable. Salary $3000. Available on short notice. New York or New England preferred. E-2668.

ELECTRO-MECHANICAL ENGINEER. Cornell; age 26; five years broad experience including two years General Electric Co. test. Desires position near New York City requiring good engineering sense and business ability combined, with good opportunity for advancement. Small growing concern preferred. E-2669.

GRADUATE ELECTRICAL ENGINEER of Robert College, Constantinople, wishes position with electrical engineering company in America. Will receive degree in June 1921. E-2670.

ELECTRICAL MECHANICAL ENGINEER, technical graduate; four years general factory maintenance and construction. Good executive; age 27. Sales proposition considered. Excellent references. Wants permanent position in any locality. E-2671.

ELECTRICAL ENGINEER, technical graduate; eight years experience in estimating, designing and installing central and substation buildings and equipment; transmission and distribution problems; electric railway and central station operation; Associate A. I. E. E. Desires permanent connection where ability and personality will gain advancement. E-2672.

DISTRICT MANAGER AND SALES ENGINEER. Technical graduate; electrical and mechanical. Age 34; married; available upon reasonable notice to build up business in industrial machinery in eastern Pennsylvania, Maryland and Virginia with headquarters in Philadelphia. Eight years experience in territory with wide acquaintance in steel mill and kindred industries. E-2673.

BUSINESS MAN. Position wanted on staff of financial, underwriting or analytical organization to investigate commercial, technical and scientific soundness of industrial, public utility and other business enterprises. Executives of broad business experience. E-2674.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate. 1915; broad exerience in design, supervision of construction, maintenance, and operation of complete hydroelectric and steam power plants, substations, and overhead and underground transmission systems. Familiar with estimating, specifications, purchasing and supervision of

drafting. Position desired with consulting engineer, public utility or contractor. E-2675.

Electrical Engineer, technical graduate; age 38; married. Fifteen years experience with best operating and engineering firms. Successful record as testing and starting engineer. At present engaged as field engineer on construction of large central station. Desires position of responsibility with central station organization or engineering firm. Present salary $4200. Assoc. A. I. E. E. E-2676.

Experimental Engineer, graduate E. E. 1917. Two years instructor in power engineering, experienced in power plant and gas producer equipment tests, desires position where permanence, fair salary and opportunity for advancement are combined. Available July 1st. E-2677.

Mathematical Electrical Engineer with considerable practical experience and some teaching experience will consider assistant professorship. E-2678.

Electrical Superintendent or maintenance engineer. Seven years industrial engineering; five years experience in manufacture and testing of wires and cables; desires connection with concern which appreciates results. Correspondence or interviews solicited. E-2679.

Electrical and Mechanical Engineer technical graduate; seventeen years experience on design, construction and operation of power plants and industrial power systems. High grade man of unusual ability who has held executive positions on projects of great magnitude. Available soon. Desires position with power company or industrial concern. E-2680.

Electrical Engineer, technical graduate; married; age 29. General Electric test experience. Electrical precipitative work. Four years experience installing and operating plant equipment. Wide experience on chemical plant equipment. Desires position as assistant superintendent or plant engineer. Salary $3000. Available on short notice. E-2681.

Sales Engineer with extensive experience in both domestic and foreign fields wishes to develop a few high grade non-interfering accounts in New York, metropolitan district and abroad, on commission basis. Electrical and mechanical products of common use especially desired. E-2682.

Graduate Electrical Engineer, ten years experience in industry, including central station industrial research, electrolysis prevention and rate studies. Also five years teaching electrical engineering. At present head of department. Desire industrial position for summer or permanently, or teaching with opportunity for research work. Member A. I. E. E. Present salary over $3400. E-2683.

Electrical Engineer, desires position as superintendent of operation and maintenance in hydroelectric plant. Five years experience as assistant to superintendent of large hydroelectric system. Experience covers construction, operation and maintenance of generating station, outdoor and indoor substations, high voltage overhead and underground transmission and general executive work. E-2684.

Chief Operating Engineer or mechanical superintendent with broad experience in safe and economical operation, maintenance of electric light, power and refrigerating plants; also large factories and buildings, having first class engineering and electrician's licenses. At present holding similar position, desires to make a change. Location anywhere before August 1st. E-2685.

Electrical and Mechanical Engineer, age 30. Ten years practical experience with mining companies as chief electrician, central stations as electrical engineer and general operation, maintenance and construction of industrial plants. At present employed, but will be available June 1st. Position as maintenance engineer of industrial plant preferred. Salary $3000. E-2686.

Technical Graduate with ten years experience in field, office and laboratory engineering with power plant equipment and electrical precipitation processes. Sales and patent experience. Desires position as development engineer or in executive capacity. E-2687.

Technical Graduate in electrical engineering, age 25; single; wishes connection with engineering, manufacturing or light and power company, affording opportunity for advancement Little experience. Locate anywhere. Available immediately. E-2688.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED APRIL 8, 1921

ABEL, LLOYD, C., Chief Engineer, Arkansas Light & Power Co., Camden, Ark.

ADRIANSON, GUS W., Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

ALEXANDER, JOHN P., Power & Mining Dept., General Electric Co., 120 Broadway, New York, N. Y.

ALLEN, GEORGE A., Transmission Engineer, Pacific Tel. & Tel. Co., 503 Telephone Bldg., Portland, Ore.

ANDERSON, CEDRIC S., Power Engineer, West Penn Power Co.; res., 4335 Dakota St., Pittsburgh, Pa.

ASHBAUGH, JOHN H., Supply Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgewood Park, Swissvale, Pa.

ASPLUND, J. W., Supt., Mountain States Power Co., Marshfield, Ore.

ATHERTON, GEORGE V., Asst. Supervisor, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1342 Penn Ave., Wilkinsburg, Pa.

ATLAS, LOUIS, Service Engineer, Westinghouse Elec. & Mfg. Co., 467 10th Ave., New York, N. Y.

BABCOCK, DAVID L., Asst. Engineer, Electrical Dept., San Francisco-Oakland Terminal Railways, 22nd & Grove Sts., Oakland, Cal.

BACHMAN, HAROLD E., Engineer, Distribution Dept., Public Service Railway Co., 80 Park Place, Newark, N. J.

BACKER, WILLIS H., Asst. Engineer, Electric Bond & Share Co., 71 Broadway, New York, N. Y.

BAKER, HARRY D., Wireman, Electrical Division, Panama Canal, Cristobal, C. Z.

BALLARD, HOWARD A., Chief Engineer, Asheville Power & Light Co.; res., 182 S. French Broad Ave., Asheville, N. C.

BALLARD, HARRY D., District Lighting Specialist, General Electric Co., 120 Broadway, New York, N. Y.

BANK, JOHN C., Sales & Illuminating Engineer, Bryan-Marsh Division, National Lamp Works, New York, N. Y.; res., 871 De Graw Ave., Newark, N. J.

BARGER, RALPH H., Engineering Dept., Stromberg-Carlson Telephone Mfg. Co.; res., 31 Rundel Park, Rochester, N. Y.

BARNES, ALBERT K., Salesman, Westinghouse Elec. & Mfg. Co., 165 Broadway, New York, N. Y.

BARR, GEORGE R., Dist. Supt. of Substations, Turners Falls Power & Electric Co.; res., 103 Revere St., Springfield, Mass.

*BEAN, ROSCOE D., Experimental & Development Work, Roller-Smith Co.; res., 47 Wall St., Bethlehem, Pa.

BEANE, HARRY E., Sales Engineer, The Bristol Co., Waterbury, Conn.; res., 513 Elliott St., Wilkinsburg, Pa.

BEARD, RALPH W., Testing Dept., Packard Electric Co., Warren, Ohio.

BEATTY, LOWELL D., Equipment Maintenance Man, American Telephone & Telegraph Co., Brushton Sta. Pittsburgh res.; 824 Hill Ave., Wilkinsburg, Pa.

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BELMONT, ARTHUR R., Asst. Engineer, Boston & Albany R. R., 268 South Station, Boston; res., Auburndale 66, Mass.

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BENSI, REYNOLD J., Testman, General Electric Co., Schenectady, N. Y.

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BJORKLUND, JOHN B., Electrical Engineer & Draftsman, Schoolhouse Dept., City of Boston; res., Dorchester, Mass.

BLAKE, FRED A., Electrical Engineer & Power Supt., Rice, Barton & Fales Machine & Iron Co.; res., 50 Hollywood St., Worcester, Mass.

BLEVINS, LEONARD C., Commercial Engineer, Westinghouse Elec. & Mfg. Co., 379 Broad St., Newark, N. J.

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BUCKLEY, JAMES L., Electrical Draftsman, Pacific Gas & Electric Co., San Francisco; res., 2408 Edwards St., Berkeley, Cal.

BURGESS, HARRY J., Power Salesman, Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

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DELANEY, AMBROSE J., Armature Winder & General Electrician, United States Fuel Co., Hiawatha, Utah.

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DRUMMOND, ALFRED H.; Stamford, Conn.

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FILSON, WALLER, Telephone Inspector, C. C. C. & St. L. Ry. Co.; res., 315 So. Sudubon Road, Indianapolis, Ind.

FINK, GUSTAVE, Junior Power Engineer, N. Y. & Queens Electric Light & Power Co., Bridge Plaza North, Long Island City; res., 315 Lenox Road, Brooklyn, N. Y.

FOCHS, HERBERT N., Electrician, Michael Borna, 100 W. 43rd St.; res., 1421 Lexington Ave., New York, N. Y.

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GILBERT, HOWARD D., Foreman of Line Dept., Worcester Electric Light Co.; res., 56 Oread St., Worcester, Mass.

GILL, WILLIAM H., Jr., Construction Electrician, Public Service Electric Co., Newark; res., 400 Davis Ave., Harrison, N. J.

GOETZE, ALEXANDER P., Engineering Dept., Western Union Telegraph Co., 195 Broadway, New York, N. Y.

GOLL, ARTHUR W., Foreman, Detroit Copper & Brass Mills, Clark Ave., Detroit, Mich.

GOVE, CHARLES M., Resident Engineer, Research Corp., 25 W. 43rd St., New York, N. Y.; res., 34 Boyden St., E. Orange, N. J.

GRAFF, JOHN T., Supt. of Results, The Chesapeake & Potomac Tel. Co.; res., 3150 Highland Ave., Washington, D. C.

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GRANVILLE, WILLIAM A., Power Plant Foreman, Salt R. V. Water Users Association, Phoenix; res., Lakeside Club, Roosevelt, Ariz.

GREENE, GEORGE S., Electrical Draftsman, Lockwood, Greene & Co., 101 Park Ave., New York, N. Y.

GREENWOOD, PHIL P., Asst. to Inspecting Engineer, The Panama Canal, 1709 G. St. N. W., Washington, D. C.

GRIEM, HARVEY, Switchboard Erector, Allis-Chalmers Mfg. Co.; res., 537 68th Ave., W. Allis, Wis.

GUHA, SURENDRA K., Foreman Electrician, The Tata Iron & Steel Works, 18, "G" Town, Jamshedpur, (Via Tatanager), India.

GUSHUE, GEORGE W., Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 826 Holland Ave., Wilkinsburg, Pa.

GUSTAFSON, GUSTAF H., Armature Winder Foreman, The Electric Service Co., Inc.; res., 905 9th Ave., Beaver Falls, Pa.

HAAS, HENRY, Tester, Consumers Power Co.; res., 311½ Fourth St., Jackson, Mich.

HALE, L. H., Electrical Estimator, E. S. Francis, 272 Asylum St., Hartford; res., 32 Connecticut Blvd., E. Hartford, Conn.

HAMBLETON, THOMAS T., D. C. Design, General Electric Co., Schenectady, N. Y.

HASTINGS, ALLEN, 2nd Operator, Big Creek No. 1, Southern California Edison Co., Big Creek, Calif.

HAWLEY, KENNETH F., Engineering Test Dept., Penna. Water & Power Co., Baltimored Md.; res., Holtwood, Pa.

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HILL, JOHN F., Salesman, Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Canada.

HILL, WILLIAM E., Superintendent & General Manager, Geneseo Gas Light Co., Geneseo, N. Y.

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WHEATLEY, RUSSELL H., Student Engineer, Testing Dept., General Electric Co.; 707 South Ave., Schenectady, N. Y.

WHEELER, PAUL V., Resident Manager, Link & Belt Co., 429 Kirby Bldg., Cleveland, Ohio.

*WILKINS, MALCOLM L., Meter Dept., & Electrical Expert, Twin State Gas & Electric Co.; res., 261 Washington St., Dover, N. H.

WILLARD, SHERWOOD H., Building Engineer, Western Electric Co., Inc., 463 West St., New York, N. Y.

WILSON, CHARLES H., Electrical Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 518 Todd St., Wilkinsburg, Pa.

WIMMER, JOSEPH, Clerk & Division Transmission Engineer, Pacific Tel. & Tel. Co., 409 Seaboard Bldg., Seattle Wash.

WINEMILLER, PRICE L., Sales Engineer, Stromberg-Carlson Telephone Mfg. Co., Kansas City, Mo.

WOODS, WILLIAM H., Asst. Engineer, Distribution Dept., Toronto Hydro-Electric System; res., 507 Brunswick Ave., Toronto, Ont., Canada.

*WORLEY, IVAN H., Paper Mill Engineer, Minnesota & Ontario Paper Co., International Falls, Minn.

WRIGHT, HARRY H. L., Checking Draftsman, Shepard Electric Crane & Hoist Co., Montour Falls, N. Y.

WYATT, JOSEPH A., District Supt., New York Telephone Co., 256 Franklin St., Hempstead, N. Y.

YOST, CHARLES Z., Engineer, Pacific Gas & Electric Co., 445 Sutter St., San Francisco, Cal.

YOUNG, LOUIS T., Electrical Draftsman, Kelman Electric & Mfg. Co., Los Angeles; res., 469 W. Oak St., Glendale, Calif.

ZIEHL, WILLIAM J., Supt., Croker Electric Co., 22 W. 30th St.; res., 1111 Quincy St., New York, N. Y.

ZINTER, JULES A., Electrical Teacher, Arsenal Technical High School; res., 2705 E. St. Clair St., Indianapolis, Ind.

ZOBEL, MAURICE L., Foreman, Fire control test room, Sperry Gyroscope Co., 40 Flatbush Ave. Extension, Brooklyn; res., 437 Home Ave., Rosebank, N. Y.

Total 418.

*Former enrolled students.

ASSOCIATES REELECTED APRIL 8, 1921

CRAMER, HARRY P., Asst. Engineer, Portland Railway, Light & Power Co., Electric Bldg., Portland, Ore.

FOULKROD, RAYMOND, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

HAYNES, WALTER, Principal, Oregon Institute of Technology, Portland, Ore.

MUIRHEAD, JAMES, Government Inspector of Electrical Energy, Province of British Columbia, Provincial Court House, Vancouver, B. C.

REDING, HENRY W., Head of Electrical Dept., Atlanta Office, Lockwood, Greene & Co., 1530 Healey Bldg., Atlanta, Ga.

WICKS, ERNEST B. E., Electrical Engineer, Rangiora Borough Council, Rangiora, N Z.

WILLMANN, WILLIAM F., Electrical Engineer, Boston Edison Co., 39 Boylston St., Boston, Mass.

MEMBERS ELECTED APRIL 8, 1921

ADAMS, CALVIN J., Local Engineer, Syracuse Office, General Electric Co.; res., 969 Lancaster Ave., Syracuse, N. Y.

BARTMESS, MEIGS W., Chief Electrical Engineer, A. B. Products Division, The National Screw & Tack Co., Cleveland, Ohio.

DICK, WALTER R. H., Electrical & Commercial Engineer, International General Electric Co., 83 Cannon St., E. C., London, Eng.

HILDEBRAND, LEE E., Electrical Engineer, General Electric Co.; res., 24 Baker St., Lynn, Mass.

HOVEY, FRANK A., Electrical Engineer, Cooley & Marvin Co., 15 Ashburton Place, Boston, Mass.

KING, HARRY M., Electrical Supervisor, Ontario Power Co., Niagara Falls, Ont., Canada.

KOPPITZ, CARL G., Vice-President & Chief Engineer, Railway & Industrial Engineering Co., Greensburg, Pa.

LUNN, ARTHUR W., Sales Engineer, General Electric Co., 671 Broad St., Newark, N. J.

MacCALLUM, CLARENCE, Electrical & Mechanical Engineer, T. Howard Barnes, 17 Battery Place, New York, N. Y.

MORGAN, CHARLES H., Manager, Northern Iowa Gas & Electric Co., Humboldt, Iowa.

NICHOLSON, FRANK C., Electrical Engineer, Lehigh & Wilkes-Barre Coal Co.; res., 125 Barney St., Wilkes-Barre, Pa.

RICHARDSON, STANLEY M., Asst. Operating Engineer, (Power), Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Canada.

FELLOW ELECTED APRIL 8, 1921

THORESEN, JETMUND J., Chief Engineer, Elektricitets Bilsynet, 1st Dist., Pilestredet 27, Kristiania, Norway.

TRANSFERRED TO GRADE OF FELLOW

ACKER, ALBERT J., Electrical Engineer of Shaw Crane Works for Manning, Maxwell & Moore, Inc., Muskegon, Mich.

EWING, DRESSEL D., Professor of Electric Railway Engineering, Purdue University, Lafayette, Ind.

FINLAY, WALTER S., Jr., Vice-President, American Water Works & Electric Co., New York, N. Y.

MACLACHLAN, WILLS, Electrical Engineer, Toronto, Ontario.

MOORE, EDWARD T., Electrical Engineer, Halcomb Steel Co., Syracuse, N. Y.

TRANSFERRED TO GRADE OF MEMBER

ABBOTT, LEWIS W., Supervisor of Equipment, New England Tel. & Tel. Co., Boston, Mass.

BARNES, HAROLD B., Chief Engineer, Golden Fleece Mining & Milling Co., Denver, Colo.

BEAUCHAMP, LEON, Vice-President and Chief Engineer, The Solex Co. Ltd., Montreal, Quebec.

BRADLEY, HAROLD H., Commercial Engineer, Latin American Sales Dept., International General Electric Co., Schenectady, N. Y.

BROWN, GEORGE N., District Manager, Pittsburgh Transformer Co., New York, N. Y.

COOPER, CHARLES P., General Manager, Ohio Bell Telephone Co., Cleveland, O.

DeFOREST, CORNELIUS W., Manager, Electrical Dept., Union Gas & Electric Co., Cincinnati, O.

FORGEE, FREDERICK A., Consulting Engineer, New York, N. Y.

HOOD, JOHN, Local Engineer, General Electric Co., San Francisco, Cal.

JONES, PHILIP C., Electrical Engineer, Goodyear Tire & Rubber Co. of California, Los Angeles, Cal.

KEARNS, J. EDWARD, Electrical Engineer, General Electric Co., Chicago, Ill.

KELLEY, WILL G., Overhead Engineer, Commonwealth Edison Co., Chicago, Ill.

LEACOCK, GEORGE D. Y., Sales Manager, Moloney Electric Co. of Canada, Ltd., Toronto, Ont.

MEYERHERM, CHARLES F., Engineer, Albert F. Ganz, Inc., New York, N. Y.

MOLONEY, T. O., President, Moloney Electric Co., St. Louis, Mo.

PATTERSON, JAMES G., Staff Engineer, New England Tel. & Tel. Co., Boston, Mass.

SCHIRTZINGER, LEO, District Manager, Century Electric Co., Cincinnati, O.

SPEIGHT, HERBERT, Superintendent of Power, Granby Consolidated Mining, Smelting & Power Co. Ltd., Anyox, B. C.

WEBER, CORNELIUS G., Assistant Engineer, Vaughn & Meyer, Milwaukee, Wis.

YOUNG, ROWLAND L., Power Engineer, Dept. of Development & Research, American Tel. & Tel. Co., New York, N. Y.

ZEHR, VRATISLAV A., Consulting, Designing, and Constructing Engineer, Pekin, Ill.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held April 1, and 14, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

BURKETT, CHARLES W., Chief Engineer, Pacific Telephone & Telegraph Co., San Francisco, Cal.
CHUBB, LEWIS W., Manager, Radio Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
CONRAD, NICHOLAS, J., Secretary-Treasurer & Manager, Schweitzer & Conrad, Inc., Chicago, Ill.
DAVIES, CHARLES E., General Traffic Superintendent, Canadian National Telegraphs, Toronto, Ont.
NEWBURY, FRANK D., Manager, Power Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
REED, HARRISON P., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
SMITH, ERNEST F., Superintendent of Substations, Commonwealth Edison Co., Chicago, Ill.
THORNTON, FRANK, JR., Manager, Electric Heating Engineering Dept., Westinghouse Elec. & Mfg. Co., Mansfield, O.

To Grade of Member

ANDERSON, E. R., Electrical Engineer, Supply Dept., General Electric Co., Schenectady, N. Y.
ATKINS, CHARLES G., Consulting Engineer, Chicago, Ill.
BELLINGER, W. F., Asst. Supt. Operations, Tests, & Repairs, Atlanta Railway & Power Co., Atlanta, Ga.
BRUBAKER, HENRY S., Construction Engineer, West Penn Power Co., Pittsburgh, Pa.
CELLAR, GEORGE A., General Supt., of Telegraph, Pennsylvania System, Philadelphia.
GOLDBERG, MAXIMILIAN M., Inventor, National Cash Register Co., Dayton, O.
GRIMSLEY, A. H., General Manager, Virginia Western Power Co., Clifton Forge, Va.
HALL, MARTIN S., Superintendent, Electrical Dept., Mathieson, Alkali Works, Saltville, Va.
HERSHEY, HARRY E., Telephone Engineer, Automatic Electric Co., Chicago, Ill.
KIDDER, HARRY A., Supt. of Motive Power, Interborough Rapid Transit Co., New York.
KNIGHT, ROBERT, Estimating Engineer, Canadian General Electric Co., Toronto.
LEFEVER, ORLAND L., General Supt., Northwestern Electric Co., Portland, Ore.
LOBECK, ADOLF J., Asst. Supt., Bronx District, N. Y. Edison Co., New York, N. Y.
MILBURN, WILLIAM R., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
NEBLETT, HERSCHEL W., Asst. Electrical Engineer, Steel & Tube Co. of America Chicago, Ill.
NICHOLSON, CHARLES M., Supt., Electrical Dept., Allis-Chalmers Mfg. Co., Milwaukee.
REDING, HENRY W., Head of Electrical Dept., Atlanta Office, Lockwood Greene & Co., Atlanta, Ga.
SKINNER, MERRILL E., Electrical Designing Engineer, Transformer Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
SNIFFIN, EDWARD H., Manager, Power Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
THOMPSON, ROSS E., Manager, Deming Ice & Electric Co., Deming, N. M.
VANDERPOEL, WILLIAM K., General Supt. of Distribution, Public Service Electric Co., Newark, N. J.
WILLMANN, WILLIAM F., Electrical Engineer, Edison Electric Illuminating Co., Boston.
WOODRESS, JAMES L., Sales Manager, Century Electric Co., St. Louis, Mo.
YOUNG, H. W., President, Delta-Star Electric Co., Chicago, Ill.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before, May 31, 1921.

Albrecht, Edwin H., Portland, Ore.
Anderson, Burton E., Oakland, Cal.
Anderson, Clifford N., W. Lynn, Mass.
Armitage, Melville, Peterboro, Ont.
Armstrong, A. H., Boston, Mass.
Bachert, Homer A., Allentown, Pa.
Bacon Roy R., White River, Ont.
Barends, Raymond E., Schenectady, N. Y.
Barrett, J. Nicolson, Cleveland, Ohio
Bartlett, Edwin N., N. Oxford, Mass.
Batcheler, Fred H., Madison, Wis.
Becker, James H., Cambridge, Mass.
Bertram, George M., Toronto, Ont.
Blackmar, Ray C., Portland, Ore.
Bond, Frank B., St. Anselme Sta., Dorchester Co., P. Q.
Borelli, Aurelio, Schenectady, N. Y.
Borshneck, C. Frank, Pittsburgh, Pa.
Bredberg, S., (Member), Schenectady, N. Y.
Bridger, Leo J., Denver, Colo.
Bryant, E. P., Saugus, Cal.
Burke, Francis X., New York, N. Y.
Burr, Henry B., Milwaukee, Wis.
Burtt, Robert B., E. Pittsburgh, Pa.
Carmichael, D. Allister, Toronto, Ont.
Carr, James A., New York, N. Y.
Carroll, Franklin O., Boston, Mass.
Carter, William L., Peterboro, Ont.
Caton, John J., Easton, Pa.
Chase, Leland H., Brooklyn, N. Y.
Christie, Donald R., Harrisburg, Pa.
Clymer, Harold B., Trenton, N. J.
Cockrill, Sterling B., Wilkinsburg, Pa.
Cole, Ira E., New York, N. Y.
Connors, Leonard M., Peterboro, Ont.
Cotton, Robert S., Peterboro, Ont.
Cramblet, Paul K., Chicago, Ill.
Crowder, Charles F., Allentown, Pa.
Davis, Sidney E., Philadelphia, Pa.
DeLanty, Benjamin F., Pasadena, Cal.
Denike, Robert E., New York, N. Y.
Derr, Edgar M., Easton, Pa.
Desai, B. C., Schenectady, N. Y.
Deutscher, Harry O., St. Louis, Mo.
Dilts, Chester W., Milwaukee, Wis.
Dovjikov, Alexander, Pittsburgh, Pa.
Duncan, A. S. Allentown, Pa.
Elmen, Gustaf W., (Member), New York, N. Y.
Emich, Harris C., Baltimore, Md.
Engel, Nathan L., (Member), Montreal, Que.
Eulenberger, Charles E., Schenectady, N. Y.
Faron, Frank A., Schenectady, N. Y.
Farrer, Henry E., New York, N. Y.
Files, Glenn W., Chicago, Ill.
Floeting, Edward R., New York, N. Y.
Flynn, P. Leo, Baltimore, Md.
Freer, George B., Jr., Utica, N. Y.
Fritz, Edwin H., Derry, Pa.
Fulmer, William A., Philadelphia, Pa.
Gerrish, Seldon W., Utica, N. Y.
Gibbons, Wiliam J., New York, N. Y.
Goob, Charles F., Baltimore, Md.
Goranson, George V., Allentown, Pa.
Grady, Frank R., Allentown Pa.
Grant, Charles E., Peterboro, Ont.
Greenamyer, Merle R., Pittsburgh, Pa.
Guthery, Marshall F., (Member), Allentown, Pa.
Hagan, H. David, Harrisburg, Pa.
Hanley, Edward L., Milwaukee, Wis.
Harman, Edwin N., Geneva, N. Y.
Hawley, Curtis B., Salt Lake City, Utah.
Held, Edward F., Bridgeport, Conn.
Hendrie, Robert A., Denison, Texas
Hotze, John W., Chicago, Ill.
Howard, Elmer F., Marion, Ill.
Howes, John C., Jr., Lynn, Mass.
Jacoby, S. Clifford, Pawtucket, R. I.
Jenks, Clifford W., Bedford, Ohio
Jones, Albert F., Denver, Colo.
Jones, John L., St. Louis, Mo.
Kaas, Hans P., New York, N. Y.
Kennard, Rollin, Great Falls, Mont.
Kettenhofen, Leo J., Chicago, Ill.
Kingsbury, William S., Bellefontaine, Ohio
Kline, E. D. G., Allentown, Pa.
Knoblock, William, Philadelphia, Pa.
Launder, John E., (Member), Kansas City, Mo.
La Barr, Myron C., New York, N. Y.
Lane, Elijah R., Chicago, Ill.
Law, Edgar D., Wilkinsburg, Pa.
Lendman, Alfred N., Kenosha, Wis.
Leonard, James G., Schenectady, N. Y.
Lyman, Van Allen, San Francisco, Cal.
Mackler, Louis, (Member), New York, N. Y.
Mangold, Alfred O., Portland, Ore.
Marshall, Arthur W., Allentown, Pa.
McCrossen, James F., Allentown, Pa.
McDaniel, Forrest V., New York, N. Y.
Meins, Paul R., Milwaukee, Wis.
Merritt, William E., Jr., E. Pittsburgh, Pa.
Mills, Russell, San Francisco, Cal.
Moore, Patrick, O., Pittsburgh, Pa.
Murphy, James W., Milwaukee, Wis.
Myers, Ralph E., (Member), Bloomfield, N. J.
Naegeli, Ernest J., (Member), Newark, N. J.
Naylor, W. K., E. Pittsburgh, Pa.
Nelson, Crescent F., New York, N. Y.
Newman, Thomas J., Canton, Ohio
North, Walter E., Allentown, Pa.
Olsen, Edward A., Alexandria, Va.
Packer, Frank W., Allentown, Pa.
Paque, E. J., Cincinnati, Ohio
Pease, Eugene I., Fort Worden, Wash.
Perry, Donald B., New York, N. Y.
Petersen, John D., Detroit, Mich.
Peterson, George H., New York, N. Y.
Peterson, Julius O., San Francisco, Cal.
Pfeil, Walter W., Newark, N. J.
Phelps, Howard S., Philadelphia, Pa.
Price, Myrl B., Portland, Ore.
Prince, Albert, Peterboro, Ont.
Ralston, Byron B., Washington, D. C.
Ranger, Alfred H., Elizabeth, N. J.
Rau, Earl S., Albuquerque, New Mexico
Reynolds, John P., Jr., Allentown, Pa.
Richmond, Carl A., New York, N. Y.
Rick, Karl L., Chicago, Ill.
Robinson, Robert McT., Louisville, Ky.
Rogers, Worth, St. Louis, Mo.
Rose, Hugh, Peterboro, Ont.
Rose, Winn M., Long Branch, N. J.
Rosenberg, Leo H., E. Pittsburgh, Pa.
Royce, Charles F., E. Pittsburgh, Pa.
Ruff, Julius J., Philadelphia, Pa.
Russell, Edward B., Kansas City, Mo.
Russin, William, Pittsburgh, Pa.
Schact, Carl, Seattle, Wash.
Schrade, W. A., Waco, Texas
Schrader, Harry W., Buffalo, N. Y.
Sexton, H. Clay, St. Louis, Mo.
Shaw, Merrille C., Philadelphia, Pa.
Sherer, Clayton M., Holtwood, Pa.
Sloan, Thomas S., Macon, Ga.
Smith, John R., Lynn, Mass.
Smith, Walter A., Jackson, Mich.
Smith, Wesley R., Allentown, Pa.
Snyder, Theodore M., Schenectady, N. Y.
Sperry, Charles S., Denver, Colo.
Stephens, Henry R., Kansas City, Mo.
Stephens, Merle R., Pittsburgh, Pa.
Strathy, Ralph L. A., Peterboro, Ont.
Sullivan, George R., Latouche, Alaska
Taylor, Thomas S., (Member), E. Pittsburgh, Pa.
Titus, Olcott, W., Hamilton, Ont.
Trombetta, Panfilo, Schenecteday, N. Y.
Turner, Merton H., Bellefontaine, Ohio
Tush, James W., Martins Ferry, Ohio
Twyford, G. T., Hagerstown, Md.
Ure, Albert R., Bingham, Utah
Walmsley, Harold M., Cincinnati, Ohio
Walter, R. G., (Member), Madison, Wis.
Webb, John B., Pittsburgh, Pa.
Webster, Dwight S., Dunkirk, N. Y.
Weil, Mabel, New York, N. Y.
Weir, Percy G., Toronto, Ont.

Westervelt, Albert F., Rutherford, N. J.
Wheeler, Edmund B., (Member), New York, N. Y.
Wheeler, Roy A., Milwaukee, Wis.
White, Kenneth, C., Pittsburgh, Pa.
White, William M., (Member), Milwaukee, Wis.
Widman, John G., Hoboken, N. J.
Williams, Richard E., Chicago, Ill.
Wilson, Golder P., (Member), E. Pittsburgh, Pa.
Winter, William A., New York, N. Y.
Winther, Peter C., Jr., Milwaukee, Wis.
Wooley, Frank E., Fulton, N. Y.
Wooley, William C., E. Pittsburgh, Pa.
Wurtz, Aldis H., Cleveland, Ohio
Wyld, Charles N., New York, N. Y.
Zboyosky, William J., Allentown, Pa.
Total 178.

Foreign

Arca, Pedro P., Buenos Aires, S. A.
Chatarji, Nabhomohan, Jamshedpore, India
Dalzell, Harold E., (Member), Arequipa, Peru
de Souza, J. T., St. Catharina, Brazil, S. A.
Glasse, Alfred O., Ongar, Essex, Eng.
Hattingh, Johannes T., Durban, Africa
Heusser, Emil, Arrau, Switzerland
Jimbo, Seikichi, Tokyo, Japan
Line, Richard, Simla, Punjab, India
Marlow, Thomas, Christchurch, N. Z.
Moss, Arthur E., Kaponga, N. Z.
Pikler, Henry, (Fellow), Budapest, Hungary
Weir, William S., Glasgow, Scotland.
Total 13.

STUDENTS ENROLLED APRIL 8, 1921

13063 Davis, John Clark, University of Kansas
13064 Adams, John T., Drexel Institute
13065 Broun, William N., Drexel Institute
13066 Burk, Raymond M., Drexel Institute
13067 Byrd, Milton F., Drexel Institute
13068 Cobb, William B., Drexel Institute
13069 Casciato, Camillo A., Drexel Institute
13070 Conner, Warren, Drexel Institute
13071 English, Ezekiel, Drexel Institute
13072 Freed, Louis J., Drexel Institute
13073 Geary, Elmer A., Jr., Drexel Institute
13074 Handshus, Charles A., Drexel Institute
13075 Jentick, Goerge A., Drexel Institute
13076 Kneisel, Fred C., Drexel Institute
13077 Knox, Garrison P., Drexel Institute
13078 Marcus, Maurice, Drexel Institute
13079 Rappold, Henry Wm., Drexel Institute
13080 Rotter, Henry M., Drexel Institute
13081 Reibrick, Paul, Drexel Institute
13082 Rittmayer, Benjamin F., Drexel Institute
13083 Schmidt, Bernard W., Drexel Institute
13084 Smealey, Charles E., Drexel Institute
13085 Titgen, William C., Drexel Institute
13086 Trainer George T., Drexel Institute
13087 Widmaier, Theo., Drexel Institute
13088 Zeitz, Morris I., Drexel Institute
13089 Gray, Samuel K., School of Engineering of Milwaukee
13090 Keys, Newall L., School of Engineering of Milwaukee
13091 Graves, Thomas E., Toronto Central Technical School
13092 Hatahway, Joseph B., Wentworth Inst.
13093 Faust, Walter L., Stevens Inst. of Tech.
13094 Murphy, Albert L., Wentworth Institute
13095 Woods, Arthur L., New York Elec. School
13096 Tkach, John, Brooklyn Polytechnic Inst.
13097 Neuberger, Arthur P., Cooper Union
13098 Miller, Harry, Cooper Union
13099 Sollie, Julius S., New York Electrical Sch.
13100 Reid, Jim B., University of Missouri
13101 Granger, Harry I., Mass Inst. of Tech.
13102 Degering, Carl A., University of Kansas
13103 Mehm, Edward C., Penn State College
13104 Callanan, Frances J., Mass. Inst. of Tech
13105 Marks, Wilford A., Armour Inst. of Tech.
13106 Smith, Arthur, New York Electrical Sch.
13107 Moxley, John A., Drexel Institute
13108 Krebs, Henry F., Drexel Institute
13109 Christopher, Dale B., Drexel Institute
13110 Harner, Charles F., Drexel Institute
13111 Kitchel, Robert S., Drexel Institute
13112 Stoudt, Adam B., Drexel Institute
13113 Herz, Monroe, Cornell University
13114 Rogers, Wilmer H., University of Kansas
13115 Mason, Warren P., University of Kansas
13116 Wellford, A. L., Jr., Mass. Inst. of Tech.
13117 McCorkendale, Ivan A., New York Electrical School
13118 Henny, George C., California Inst. of Tech.
13119 Inskip, Leonard S., Rensselaer Poly. Inst.
13120 Bush, George H., Kansas State Agri. Coll.
13121 Bucklee, Wm. John, Kansas State Agricultural College
13122 Manry, Thornton J., Kansas State Agricultural College
13123 Hockman, Herman C., Kansas State Agricultural College
13124 Jennings, Ralph S., Kansas State Agricultural College
13125 Rossel, Lee E., Kansas State Agri. Coll.
13126 Crow, Roland M., Kansas State Agri. Coll.
13127 Domoney, Earl R., Kansas State Agricultural College
13128 Bradley, Walter Raymond, Kansas State Agricultural College
13129 Ford, Asa H., Kansas State Agri. Coll.
13130 Sinderson, Leland O., Kansas State Agricultural College
13131 Elliott, Richmond K., Kansas State Agricultural College
13132 Watkins, Millard C., Kansas State Agricultural College
13133 Nay, Harold S., Kansas State Agri. Coll.
13134 Beyer, Joseph E., Jr., Kansas State Agricultural College
13135 Phillips, Paul J., Kansas State Agri. Coll.
13136 Nordeen, Frank E., Kansas State Agricultural College
13137 Garloch, Gerald Lynn, Kansas State Agricultural College
13138 Staib, Harry John, Kansas State Agricultural College
13139 Glendening, George McG., Kansas State Agricultural College
13140 Cook, Morris H., University of Illinois
13141 Abbott, Howard H., Carnegie Institute of Technology
13142 Nelson, Paul V., Mich. Agricultural Coll.
13143 Maitland, Roy M., Michigan Agri. Coll.
13144 Johnson, Frank August, Michigan Agricultural College
13145 Wismer, Edwin W., Westinghouse Technical Night School
13146 Snyder, Harry W., University of Illinois
13147 Wendel, David D., Alabama Poly. Inst.
13148 Rosenberg, I. M., College of the City of New York
13149 Finch, Norman L., Toronto Central Technical School
13150 Ballantyne, William R., Central Toronto Technical School
13151 Doel, Arthur D., Toronto Central Technical School
13152 Wolfe, Samuel E., Toronto Central Technical School
13153 Wilson, John G., Toronto Central Technical School
13154 Stephens, Sidney G., Jr., Toronto Cnetral Technical School
13155 Usher, Harold L., Toronto Central Technical School
13156 Gerling, Arthur, University of California
13157 Hall, Raymond A., University of Calif.
13158 Emlen, Andrew A., University of California.
13159 Fillinger, Raymond C., Univ. of Calif.
13160 Campbell, Colin C., University of Calif.
13161 Cantlen, James S., University of California
13162 Clark, Lewis F., University of California
13163 Welty, Carl D., University of California
13164 Smith Charles S., University of California
13165 Harding, John P., University of California
13166 Herrman, Walter J., University of Calif.
13167 Phelan, Roy N., University of California
13168 Landon, Francis L., University of Calif.
13169 Ruby, Scott R., University of California
13170 Sharp, Hubert, University of California
13171 Scott, George Jr., University of California
13172 Rush, Orlof, E., University of California
13173 Spease, John F., University of California
13174 King, Francis M., University of Kansas
13175 Orner, Martin, City College of New York
13176 Long, Wilfred F., New York Elec. School
13177 Chisholm, Charles F., Johns Hopkins Univ.
13178 Kellner, William S., Drexel Institute
13179 Warfield, Calvin N., Johns Hopkins Univ.
13180 Hurwitz, Abraham, Johns Hopkins Univ.
13181 Shapiro, Arthur, Johns Hopkins Univ.
13182 Smith, Bernard R., Johns Hopkins Univ.
13183 Schmidt, Charles J., Johns Hopkins Univ.
13184 Allen, Thomas J., Georgia School of Tech.
13185 Malti, Michel G., Georgia School of Tech.
13186 Brunson, L. L., Georgia School of Tech.
13187 Camp, Leon K., Georgia School of Tech.
13188 Stambaugh, Norman F., Georgia School of Technology
13189 Simpson, Stanley S., Georgia School of Technology
13190 Wylie, Ward, Michigan Agricultural Coll.
13191 Randolph, William J., Drexel Institute
13192 Kohl, William C., Mass. Inst. of Tech.
13193 Cressy, Dustin G., Northeastern College
13194 Kimberly, Mervyn C., University of Nebr.
13195 Cronk, Seymour H., University of Kansas
13196 McCormick, Frank A., Drexel Institute
13197 Greenwald, Harold P., Carnegie Institute of Technology
13198 Bernard, Wilfred N., New York Elec. School
13199 Doolittle, Frederick B., University of Colo.
13200 Thomas, Earl E., Kansas State Agri. Coll.
13201 Culver, Henry C., Wentworth Institute
13202 Biavath, Joseph, Cooper Union
13203 Brennecke, Robert A., Cooper Union
13204 Cooper, Samuel, Cooper Union
13205 Cohen, Philip, Cooper Union
13206 Drury, Thomas J., Cooper Union
13207 Gamm, O. E., Cooper Union
13208 Hajos, Eugene, Cooper Union
13209 Hopf, Rudolph, J., Cooper Union
13210 Hysko, John L., Cooper Union
13211 Lipenholtz, Harry, Cooper Union
13212 Morrison, Staats D., Cooper Union
13213 Owsald, James, Cooper Union
13214 Smith, Albert M., Cooper Union
13215 Spencer, Boris M., Cooper Union
13216 Stumpf, William Jr., Cooper Union
13217 Walther, Lawrence A., Cooper Union
13218 Waissman, Leon, Cooper Union
13219 Davis, Philip, Tri-State College
13220 Keiller, Thomas M., Mass. Inst. of Tech.
13221 Saunders, Alfred W., Newark College of Technology
13222 Taylor, Edmund R., Johns Hopkins Univ.
13223 Edelson, Leon, Johns Hopkins University
13224 Clark, George D., Ohio State University
13225 Copenhafer, John B., Ohio State Univ.
13226 Eyler, Rayner D., Ohio State University
13227 Friederich, Eitel J., Ohio State University
13228 Headapohl, Vernon F., Ohio State Univ.
13229 Kimberly, Emerson E., Ohio State Univ.
13230 Lomberger, Edward H., Ohio State Univ.
13231 Panek, Jaro J., Ohio State University
13232 Smith, James Y., Ohio State University
13233 Fouts, Walter E., Ohio State University
13234 Hathaway, Clarence R., Ohio State Univ
13235 Houck, William S., Pratt Institute
13236 Battey, Leslie J., University of Illinois
13237 Ryder, Herbert S., Tri-State College
13238 Cleveland, Francis D., Jr., Sheffield Scientific School
13239 Hanson, Edward C., New York Elec. School
13240 Laufer, Edward S., Stevens Inst. of Tech.
13241 Hanks, R. M., West Virginia University
13242 Stump, Wilbur D., West Virginia Univ.
13243 Tutt, Bland R., University of Missouri
13244 Calvert John F., University of Missouri
13245 Austry, William H., University of Mo.
13246 Heidbreder, Carl G., University of Mo.
13247 Harvey Fred T., University of Missouri
13248 Gartner, Charles E., Jr., Drexel Institute
13249 Cruzen, Fred T., Montana State College
13250 O'Donnell, John J., Pratt Institute
13251 Cummings, John S., Mass. Inst. of Tech.
13252 Smith Albert Van D., Johns Hopkins Univ.
13253 Williams, Percy H., University of Minn.
13254 Ziegler, Arthur W., University of Illinois
13255 Lackland, Robert E., University of Illinois
13256 Dougherty, James A., Drexel Institute
13257 Greene, Arthur D., Georgia School of Tech.
13258 Wallace, Edward V., Georgia School of Tech.
13259 Khoury, Michael A., Georgia School of Technology
13260 Stakely, William N., Georgia School of Technology
13261 Cox, William T., Georgia School of Tech.
13262 D'Arcy, James Jr., Georgia School of Tech.
Total 200.

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Voltage and Current Harmonics Caused by Corona

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THE FOLLOWING investigation was made to study the effects of corona in producing voltage and current harmonics in transmission systems.

In the early work on corona in 1910 a very complete oscillographic study was made of voltage and current. It was found that the current wave of corona loss very much resembled the excitation current wave of a transformer or iron-core reactor. A typical corona wave is shown in Fig. 1.[1] This wave has a very prominent third harmonic.

In 1919 three-phase corona losses were measured up to about 220 kv. on a line approximately 100 miles long.[2] The corona losses, within the accuracy of such measurements, checked very well with the quadratic law. An interesting part of this investigation was the discovery of very large triple-frequency

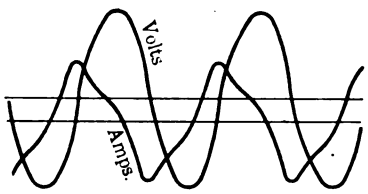


FIG. 1—CORONA CURRENT—SINGLE-PHASE

currents in the neutral of the grounded Δ Y transformers. This current was in every respect similar to the triple-frequency excitation current found in Y Y grounded neutral transformers. One explanation for its existence would be the amplification of slight residual triple-frequency excitation voltages in Δ Y transformers by the high capacity of the line. It seemed, however, as the result of the early work referred to above, that the harmonic was caused by corona loss over each half cycle.

When an alternating voltage higher than the critical corona voltage is applied to a conductor the loss starts at a given point during each half cycle as the voltage increases, continues over part of the half cycle, and finally ends at a given point as the voltage decreases. A varying amount of corona and loss thus occurs during a given part of each voltage wave. The conducting corona, in effect, makes a conductor which periodically varies in diameter. The capacity and loss, therefore, vary during parts of each wave. It follows that if a sine wave voltage high enough to cause corona loss is applied to conductors the current cannot follow a sine wave but must be distorted or contain harmonics. Fig. 1 shows that such a wave

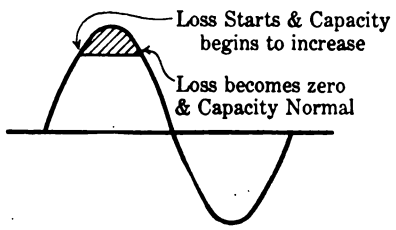


FIG. 2

contains a prominent third. The phenomenon is, in fact, very similar to that of distortion in the exciting current wave where distortion occurs chiefly due to changing permeability during each half cycle.

When corona loss occurs on three-phase lines with grounded neutral, three single-phase paths are afforded for the triple-frequency component of the current through the lines, the capacity to ground, the ground and the neutral ground connection as shown in Fig. 3.

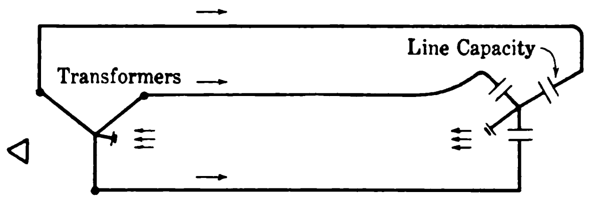


FIG. 3—THREE SINGLE-PHASE PATHS FOR CORONA TRIPLE-FREQUENCY CURRENT

If a transformer with a grounded neutral is used at the receiving end part of the current may also be supplied through the transformer. The triple-frequency currents cannot flow in the lines if the neutral is not grounded. This follows because the triple-frequency components are 3×120 deg. = 360 deg. apart or in phase. Fundamentally the sum of the currents flowing to the neutral point must be zero. Since the currents are in phase the triple component can satisfy

1. Peek, "Law of Corona and Dielectric Strength of Air," A. I. E. E., June 1911, "Dielectric Phenomena," pp. 113, 207.

2. W. W. Lewis "Some Corona Loss Tests," *General Electric Review.* May 1920. "Some Transmission Tests," A. I. E. E., June, 1921.

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

this condition only when it is zero; it can flow over the lines only when single-phase paths are afforded through the grounded neutral. Since with a sine wave voltage the corona current inherently contains a third harmonic the voltage between line and neutral must be distorted if this component is suppressed. Higher odd harmonics are also caused by corona. With symmetrically arranged conductors, however, only the third and odd multiples of the third can appear on the lines.

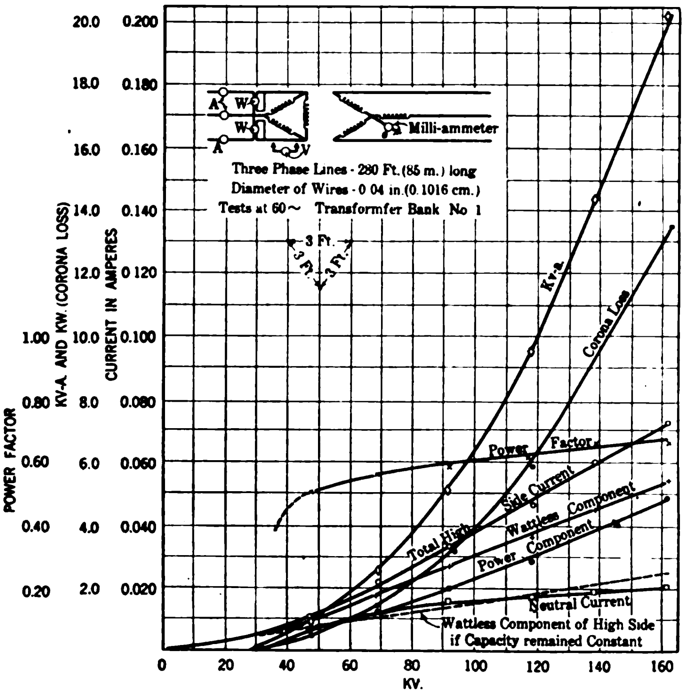


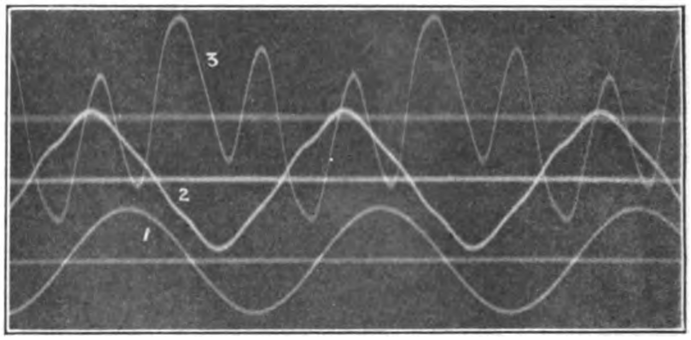
FIG. 4—CORONA CHARACTERISTICS OF A THREE-PHASE LINE WITH Δ Y GROUNDED NEUTRAL TRANSFORMERS

Tests were made on short three-phase lines of very fine wire so that the corona loss would be excessive and exaggerate conditions. The transformers were of such a size that the corona loss was an appreciable load. A sine wave voltage was used. There was a large triple-frequency current in the neutral.

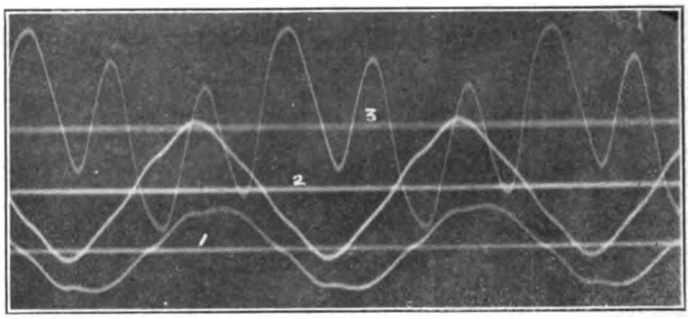
After curves were made on the line similar curves were made on Y-connected glass plate condensers of approximately the equivalent capacity of the line and of very small corona loss. The neutrals of the condensers and the transformers were connected together.

These tests were made to determine if the capacity of a line free from corona loss could cause high triple-frequency currents by amplification of residual triple-frequency magnetizing voltage harmonics in the Δ Y transformers. There were no appreciable neutral currents when the condensers were used.

Fig. 4 gives a set of curves showing the corona characteristics of a three-phase line with Δ Y-connected, grounded neutral transformers at the generating end and open-circuited at the receiving end. All of the measurements, with the exception of the line and neutral currents, were made on the low side but are corrected for losses and referred to the high side. The high side or capacity current starts at zero and increases in a straight line until the corona point is reached. The current then increases much more rapidly than the voltage. This increase in current is caused by a loss component and an added reactive component. The two components are plotted. It is seen that the apparent capacity of the line increases very rapidly with increasing voltage above the corona point. This is seen by referring to the dotted line which would represent the capacity current if there were no apparent increase owing to corona. To account for the reactive component it is necessary to assume that the apparent conductor diameter has increased from 0.102 cm. to 8.0 cm. or about 80 times at 150 kv. The neutral current starts at the beginning of corona loss and soon reaches a value which is comparable to the line current.



A—1. Low side voltage between lines.
2. High side line current.
3. Neutral current.



B—1. Low side line current.
2. High side line current.
3. Neutral current.

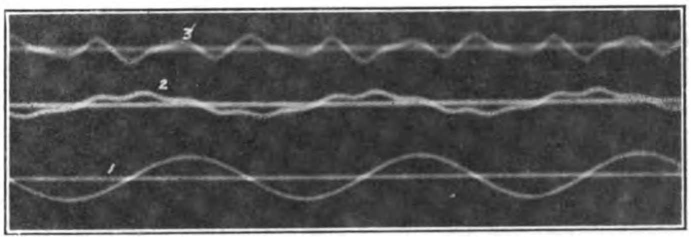
FIG. 5—ΔY TRANSFORMERS AND LINES—NO STEP-DOWN TRANSFORMERS

150 kv., 60 ~ applied to lines—Transformer Bank No. 1
(See Fig. 4)

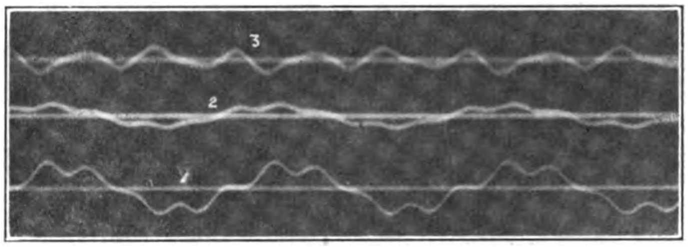
Fig. 5 shows waves of low side voltage and line and neutral currents at 150 kv.

The generator voltage is a very good sine wave. The neutral current contains a very pronounced third harmonic superposed on residual fundamental. The fundamental component in the neutral is caused by lack of exact symmetry in the lines or transformers. Fig. 6 shows a similar set of curves taken at 32.4 kv.

The curves in Fig. 7 were made in the same way as those in Fig. 4 except that three banks of glass plate condensers connected in Y were substituted for the line. The condenser neutral was grounded and con-



A—1. Low side voltage between lines.
2. High side line current.
3. Neutral current.



B—1. Low side line current.
2. High side line current.
3. Neutral current.

Fig. 6—Δ *Y* Transformers and Lines—No Step-Down Transformers

32.4 kv., 60 ~ applied to lines—Transformer Bank No. 1
(See Fig. 4)

nected to the transformer neutral. There was a slight corona loss on the condensers and leads. The neutral current is practically negligible. What there is, is probably due to the slight corona loss. Figs. 8 and 9 show the current waves at 110 and 150 kv.

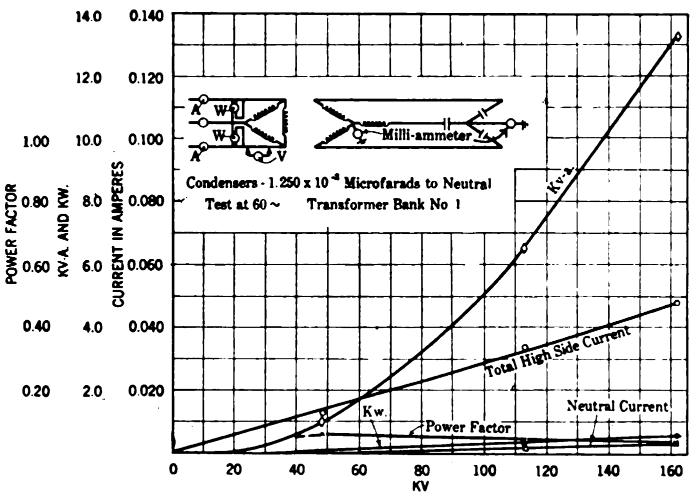
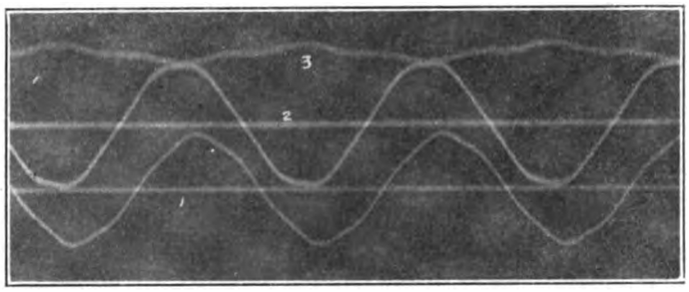


Fig. 7—Capacity Load on Δ *Y* Grounded Neutral Transformers

The neutral current wave at 150 kv. is interesting. It appears as a hump at the maximum of the voltage wave due to corona loss on the leads and edges of the plates. This loss does not appreciably change the capacity as in the case of corona on the wires.

Fig. 10 gives corona characteristics of a line with the transformers connected Δ Δ. The corona loss is not appreciably changed by suppression of the triple-frequency current.

A set of characteristic curves similar to those in Fig. 4 was made with a transformer of lower reactance. See Fig. 11. The general characteristics are very much the same. The neutral current is

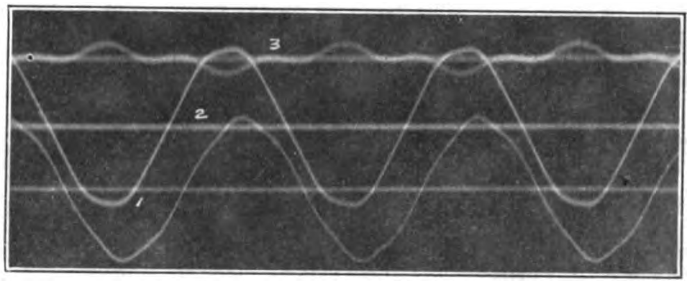


1. Low side line current.
2. High side line current.
3. Neutral current.

Fig. 8—Δ*Y* Transformers and Condensers in *Y*—Transformer and Condenser Neutrals Connected—No Lines

110 kv., 60 ~ applied to condensers.
Transformer Bank No. 1.
(See Fig. 7.)

less, however. The neutral current wave, as shown in Fig. 12, in addition to the third and fundamental contains a decided ninth. There is thus, apparently, a chance of amplification of the corona harmonics by the transformer reactance. The neutral current would, therefore, be expected to vary with the circuit constants.



1. Low side line current.
2. High side line current.
3. Neutral current.

Fig. 9—Δ *Y* Transformers and Condensers in *Y*—Transformer and Condenser Neutrals Connected—No Lines

150 kv., 60 ~ applied to condensers.
Transformer Bank No. 1.
(See Fig. 7.)

With a condenser load the currents were the same as in Fig. 7. The neutral current wave is shown in Fig. 13.

In Fig. 14 Δ *Y* grounded neutral transformers were placed on the step-down or receiving end. It will be noted that the greater part of the neutral current is supplied from the generator end. The waves are shown in Figs. 15 and 16. The neutral current of the receiving end contains a third and ninth. Fig. 17 gives the same wave with the load disconnected.

The measured and calculated corona loss curves, given in Fig. 18, check very well, especially when the small size of the wire is considered. The quadratic law used in making these calculations is given in the appendix.[3] This reduces to the form ordinarily used when the wires are large. While these measurements

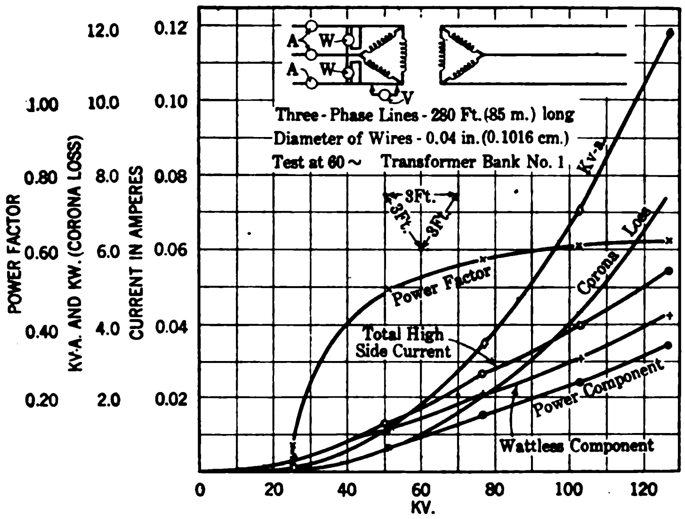


FIG. 10—CORONA CHARACTERISTICS OF A THREE-PHASE LINE WITH ΔΔ TRANSFORMERS

were made under conditions favorable for accuracy they emphasized the difficulty in obtaining accurate measurements on long three-phase lines. The deviation from the calculated curve is due to wave shape changes.

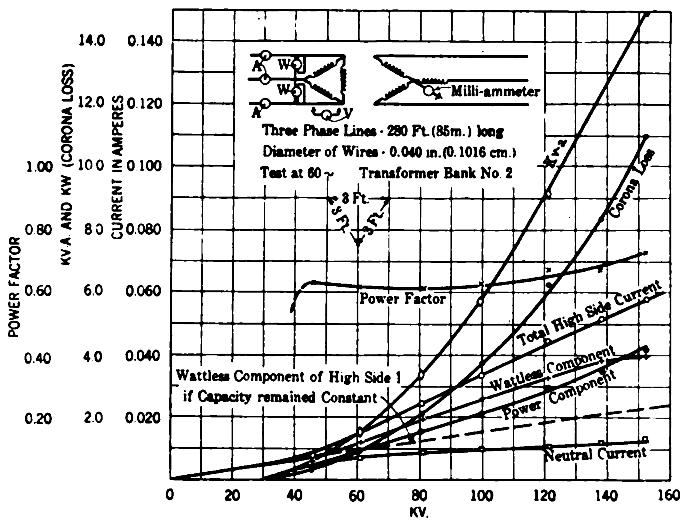


FIG. 11—CORONA CHARACTERISTICS OF A THREE-PHASE LINE WITH Δ Y GROUNDED NEUTRAL TRANSFORMERS

CONCLUSIONS

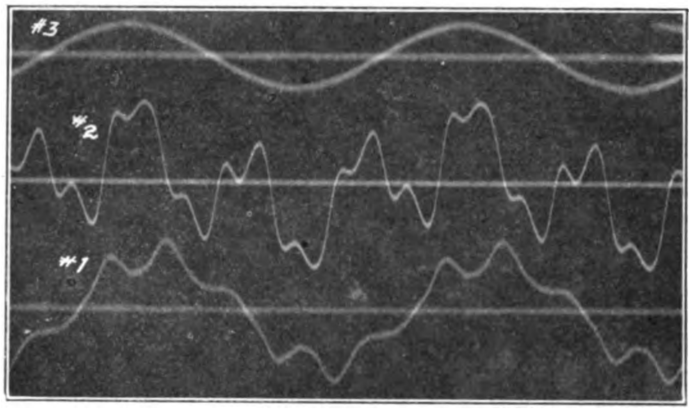
Corona will cause voltage and current harmonics, of which the third is the most prominent.

When Δ Y grounded neutral transformers are used, the third and odd multiples of the third harmonic, such as the ninth, may flow in the neutral.

The neutral corona current will not be greater for several grounds than for a single ground.

If the neutral is not grounded, distortion of the voltage may be expected.

The harmonic neutral currents may be of the order



1. Low side line current.
2. Neutral current.
3. Low side voltage.

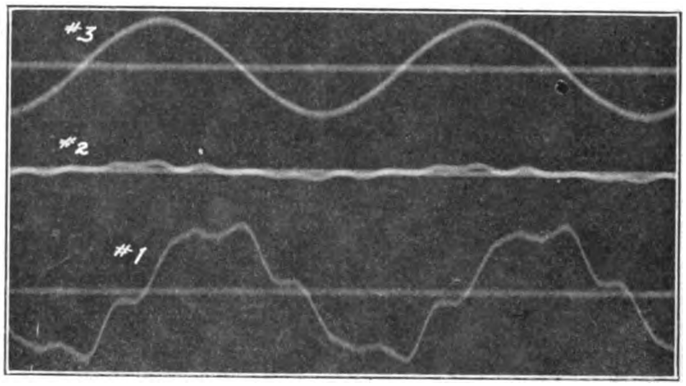
FIG. 12—Δ Y TRANSFORMERS AND LINES—NO STEP-DOWN TRANSFORMERS

100 kv., 60 ~ applied to lines.
Transformer Bank No. 2.
(See Fig. 11.)

of the capacity current of the line when the corona loss is excessive.

In properly designed practical transmission lines, the harmonic introduced by corona should be inappreciable.

The apparent capacity of the line increases rapidly



1. Low side line current.
2. Neutral current.
3. Low side voltage.

FIG. 13—Δ Y TRANSFORMERS AND CONDENSERS IN Y—TRANSFORMERS AND CONDENSER NEUTRALS CONNECTED—NO LINES

100 kv., 60 ~ applied to condensers.
Transformer Bank No. 2.

above the corona point. At 150 kv. the capacity current is equal to that for conductors of 80 times the radius of the one used.

The above tests were purposely made with very small wire and high voltage in order to exaggerate the effects of corona.

3. Peek, "Dielectric Phenomena in High-Voltage Engineering," page 136.

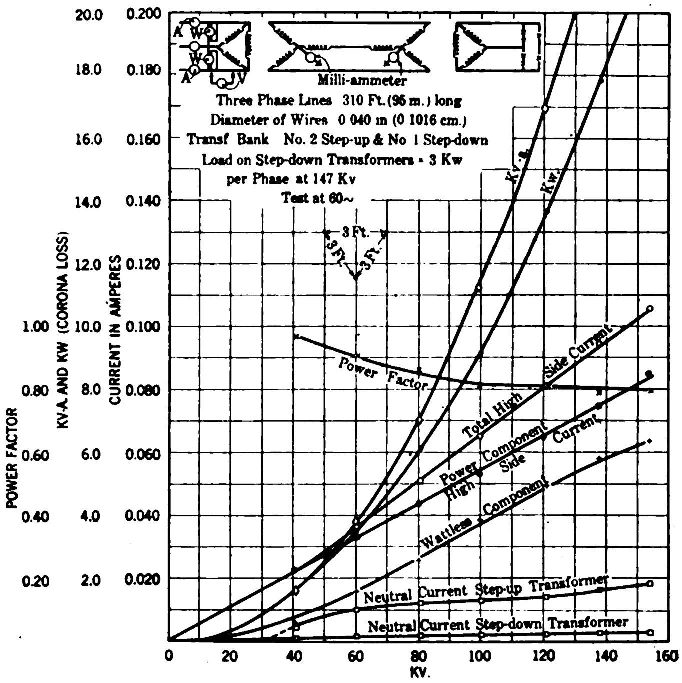
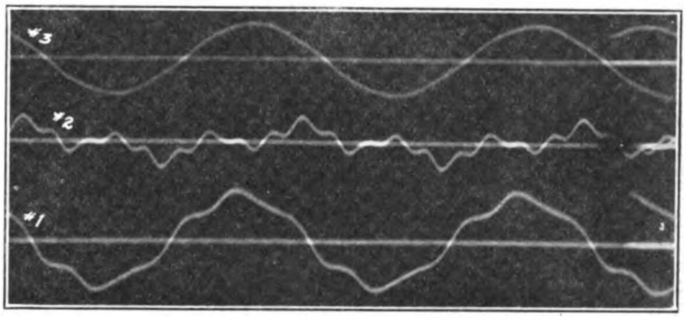


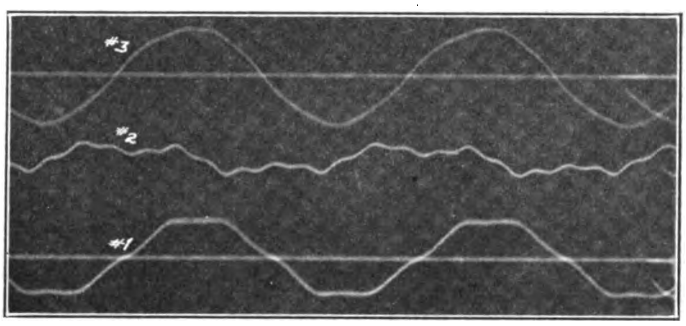
FIG. 14—CORONA CHARACTERISTICS OF A THREE-PHASE LINE WITH ΔY GROUNDED NEUTRAL TRANSFORMERS AT STEP-UP END AND $Y\Delta$ GROUNDED NEUTRAL TRANSFORMERS WITH LOAD AT STEP-DOWN END



1. Low side current.
2. Neutral current—Step-down transformers.
3. Low side voltage—Step-down.

FIG. 15—Δ Y TRANSFORMER BANK NO. 2, LINES, Y Δ STEP-DOWN TRANSFORMER BANK NO. 1.

150 kv., 60 ~ applied to lines—with load. Both neutrals grounded. (See Fig. 14.)



1. Low side current.
2. Neutral current—Step-up end.
3. Low side current—Step-down.

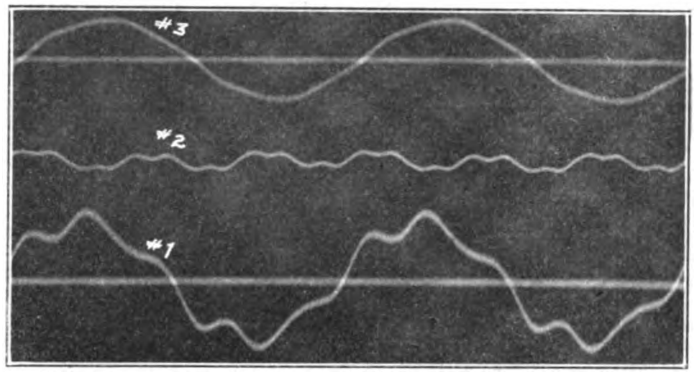
FIG. 16—Δ Y TRANSFORMER BANK NO. 2, LINES, Y Δ STEP-DOWN TRANSFORMER BANK NO. 1

32.4 kv., 60 ~ applied to lines—with load. Both neutrals grounded. (See Fig. 14.)

The harmonics are affected to some extent by the transformer constants.

Calculated and measured corona losses checked very well.

Thanks are due Mr. W. L. Lloyd, Jr. for assistance in making tests and calculations.



1. Low side current.
2. Neutral current—Step-down end.
3. Low side voltage—Step-down end.

FIG. 17—Δ Y TRANSFORMER BANK NO. 2, LINES, Y Δ STEP-DOWN TRANSFORMER BANK NO. 1—NO LOAD

150 kv., 60 ~ applied to lines. Both neutrals grounded—no load.

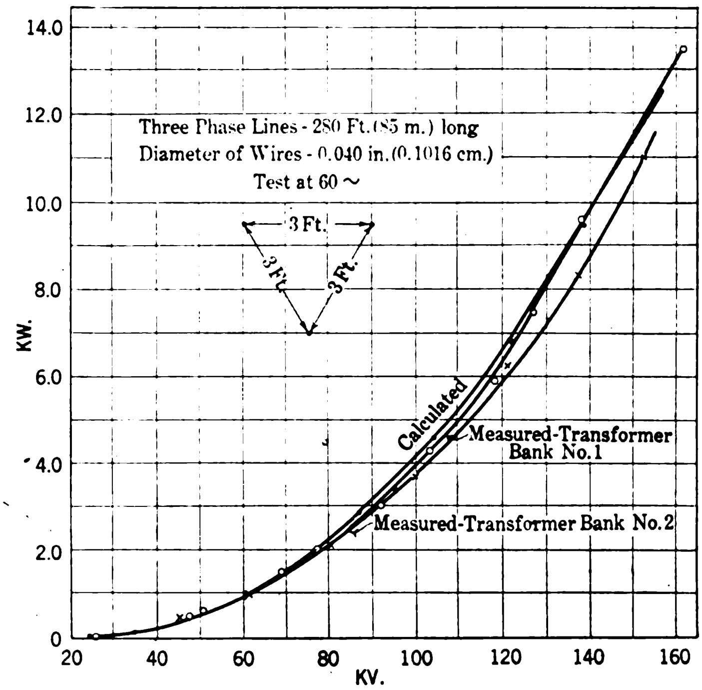


FIG. 18—CALCULATED AND MEASURED CORONA LOSS ON THREE-PHASE LINES

APPENDIX

TRANSFORMERS

Bank No. 1

Each Transformer, 10 kv-a., 400/100,000 volts, 25 ~. Resistance low side, 0.08 ohms. Resistance high side, 15,400 ohms.

Reactance reduced to high side, 116,000 ohms at 60 ~

Bank No. 2.

Each Transformer, 10 kv-a., 440/100,000 volts, 60 ~.

Resistance low side, 0.042 ohms. Resistance high side, 5,760 ohms.

Reactance reduced to high side, 32,000 ohms.

Line

New copper wire. Diameter 0.040 inches (0.102 cm.). Wires arranged in a triangle at 3 ft. (91 cm.) spacing. Length of each wire 280 ft. (85 m.)

Condensers

Glass plates in air.

Capacity to neutral. $1.25 \times 10^{-3}\ \mu$ f.

Quadratic Law

$$p = 241\,(f + 25)\sqrt{\frac{r + 6/s + 0.04}{s}}\,(e - e_d)^2$$

10^{-5} kw. per km. per wire

$$g_d = g_0\,\delta\left[\left(1 + \frac{0.30}{\sqrt{\delta\, r}}\right) \times \frac{1}{(1 + 230\, r^2)}\right]$$

$e = m_0\, g_d\, r \log_e s/r$

s = spacing in cm.

r = radius in cm.

$m_0 = 0.95$

$\delta = \dfrac{3.92\, b}{273 + t}$ b = bar. pressure cm. t = temp. deg. cent.

$p = 0.00217\,(e - 14.)^2$ kw.

TABLE I

Step-up Transformers—No step-down Transformers

Bank No. 1* Δ Y Connection

Temp. = 21. deg. cent. Bar. Press. = 29.237 in. δ = 1.010

No-Load

	Low Side					High Side				
Volts†	Amperes	Kw.	Kv-a.	Power Factor	Kv.	Amperes	Kw.	Kv-a.	Power Factor	Neut. Amperes
				Lead.						0
352	4.69	0.697	2.86	0.24	152.0					0
202	2.55	0.260	0.89	0.29	87.1					0
105	1.15	0.085	0.205	0.41	45.3					
				Bank No. 1	Δ Y	Lines on.		See Fig. 4.		
				Lead.						
352	35.4	14.52	21.6	0.68	161.0	0.0727	13.48	20.3	0.664	0.0208
304	29.5	10.16	15.5	0.66	138.0	0.0602	9.54	14.4	0.662	0.0189
256	23.3	6.40	10.3	0.62	118.0	0.0468	5.85	9.56	0.612	0.0172
201	16.6	3.38	5.76	0.59	91.1	0.0331	3.05	5.22	0.585	0.0151
152	11.1	1.64	2.92	0.56	68.6	0.0216	1.45	2.56	0.567	0.0119
105	5.9	0.55	1.07	0.51	47.0	0.01105	0.457	0.898	0.509	0.0068
				Bank No. 1		Condensers on in Y.		See Fig. 7.		
				Lead.						
354	25.2	1.34	15.5	0.086	162.0	0.0476	0.485	13.35	0.0364	0.0025
247	17.6	0.66	7.52	0.088	113.0	0.0335	0.214	6.56	0.0326	0 †
107	7.3	0.16	1.35	0.118	48.6	0.01225	0.059	1.03	0.0573	0

*Operated at 60 cycles.

†Phase voltage balanced throughout tests. No variation measured.

Phase current slightly unbalanced. No-load ± 1.0 per cent variation in phase current.

With Lines on ± 1.5 per cent " " " "

With Condensers ± 0.5 per cent " " " "

TABLE II

Step-up Transformers—No Step-down Transformers.

Bank No. 1. Δ Δ Connection

Temp. = 21 deg. cent. Bar. Press. = 29.237 in. δ = 1.010

No-Load

	Low Side					High Side				
Volts	Amperes	Kw.	Kv-a.	Power Factor	Kv.	Amperes	Kw.	Kv-a.	Power Factor	Neut. Amperes
498	3.92	1.16	3.38	0.34	125.0					
405	3.20	0.80	2.24	0.36	101.0					
305	2.38	0.480	1.26	0.38	76.3					
201	1.49	0.228	0.518	0.44	50.2					
104	0.66	0.073	0.119	0.61	26.0					
				Lines on.	Fig. 10	Bank No. 1.				
500	17.2	8.68	14.9	0.58	127.0	0.0540	7.45	11.88	0.627	
403	13.0	5.12	9.08	0.56	103.0	0.0397	4.28	7.08	0.604	
303	8.82	2.50	4.63	0.54	77.1	0.0260	2.00	3.47	0.576	
201	4.76	0.800	1.66	0.48	50.9	0.01309	0.568	1.154	0.493	
102	1.47	0.083	0.26	0.32	25.7	0.00350	0.010	0.1558	0.0642	

† ± 1 per cent variation in line currents of the three phases.

No variation in voltage between lines.

*Operated at 60 cycles.

TABLE III

Step-up Transformers—No Step-down Transformers.
Bank No. 2 Transformers Δ Y
Temp. = 21 deg. cent. Bar. Press. = 28.63 in. δ = 1.030
No-Load

	Low Side					High Side				
Volts	Amperes†	Kw.	Kv-a.	Power Factor	Kv.	Amperes	Kw.	Kv-a.	Power Factor	Neut. Amperes
				Leading						
382	2.89	1.88	1.91	0.985	151.0					0
344	2.76	1.54	1.64	0.97	136.0					0
303	2.56	1.22	1.34	0.91	119.0					0
250	2.22	0.870	0.961	0.90	98.5					0
202	1.87	0.588	0.654	0.90	79.5					0
152	1.50	0.350	0.395	0.95	59.8					0
102	1.03	0.177	0.182	0.97	39.8					0
				Bank No. 2	Lines on.		See Fig. 11			
384	27.6	13.64	18.4	0.74	153.0	0.0639	11.66	16.92	0.689	0.0145
382	25.0	12.92	16.5	0.78	152.0	0.0573	10.96	15.10	0.728	0.0133
344	22.6	9.94	13.5	0.74	138.0	0.0518	8.33	12.4	0.672	0.0120
305	19.8	7.50	10.5	0.71	121.0	0.0442	6.23	9.26	0.673	0.0111
250	15.4	4.54	6.66	0.68	99.6	0.0336	3.64	5.79	0.628	0.0099
203	11.5	2.72	4.03	0.68	80.9	0.0248	2.12	3.47	0.611	0.0087
152	7.3	1.34	1.92	0.70	60.3	0.0152	0.98	1.59	0.617	0.0068
114	4.3	0.60	0.85	0.70	45.2	0.00791	0.39	0.619	0.630	0.0045

†Line current varied in the different phases by $\pm$ 5 per cent at the high voltages, $\pm$ 2 per cent at low voltages for no-load; $\pm$ 2 per cent both high and low voltages with lines on.
No variation in voltage between lines.

TABLE IV

Load on Step-down Transformers.
Step-up Transformers.

	Low Side				High Side					Neutral Current	
Volts	Amperes†	Kw	Kv-a.	Power Factor	Kv.	Amperes	Kw.	Kv-a.	Power Factor	Step-up	Step-down
386	44.1	24.68	29.5	0.84	154.0	0.1053	22.53	28.1	0.802	0.0175	0.0025
345	39.6	19.56	23.7	0.82	138.0	0.0942	17.80	22.5	0.792	0.0159	0.0025
303	34.5	15.04	18.1	0.83	121.0	0.0812	13.66	17.0	0.803	0.0138	0.0020
251	27.8	10.08	12.1	0.83	100.0	0.0650	9.10	11.26	0.808	0.0126	0.0020
202	21.7	6.92	7.58	0.91	80.8	0.0504	6.09	7.06	0.863	0.0118	0.0020
153	15.9	3.84	4.22	0.91	60.4	0.0366	3.45	3.82	0.903	0.0099	0.0015
103	10.0	1.76	1.78	0.99	41.0	0.0228	1.57	1.62	0.968	0.0045	0.0010

†Line Current in the different phases varied by $\pm$ 3 per cent.
No variation in voltage between lines.

TELEGRAPHY AND TELEPHONY NOTES

M. A. Noss, heretofore engineer, has been appointed chief engineer of the Telepost Company, New York. In association with P. B. Delany, Mr. Noss is engaged in wire and radio communication research.

George H. Clark, engineer with the Radio Corporation of America, has gone to South America on a business trip.

Joseph W. Milnor, engineer with the Western Union Telegraph Company, is at work on an Institute paper dealing with the subject of "Ocean Cable Telegraphy" which it is expected will be ready for presentation next Fall.

The Standardization Committee of the Institute of Radio Engineers, composed of twenty-five prominent radio engineers, is at work on a complete revision of the definitions of the technical terms which have come into use in the radio art within the past few years. It is expected that the Committee's report will be ready for publication in book form by October or November this year.

In the lobby on the tenth floor at A. I. E. E. headquarters, New York, hangs a large size engraving of a painting showing S. F. B. Morse, inventor of the telegraph, exhibiting to a group of the leading scientists of his time the first model of the telegraph. The picture was donated to the Institute on June 27, 1912, by General Edward H. Ripley.

A master clock has been developed in Plainfield, N. J. by T. S. Casner and O. L. Badger, which is automatically corrected by the radio impulses sent out from Washington each day at noon. This clock can control a number of secondary clocks and a correction in time of the master clock by the radio signals corrects all of the secondary clocks which it controls. Heretofore the only method of automatic correction of clocks was by wire circuits to which all of the clocks to be corrected were connected.

Voltage and Power Factor Control of 66,000-Volt Transmission Lines Connecting Two Generating Stations

BY RAYMOND BAILEY

The Philadelphia Electric Company

The problem which confronted The Philadelphia Electric Company of providing for the control of voltage and power factor of the two 66,000-volt transmission lines connecting its Schuylkill and Chester generating stations is presented in this paper.

It is required that the control of voltage and power factor of the transmission lines referred to permit of the transfer of energy in either direction, at suitable power factor, up to the rated kv-a. capacity of the lines, with the generating stations operating at approximately equal bus voltages. The situation is considerably complicated by the necessity for supplying energy to several industrial substations, connected to these lines near the midpoint, which under certain operating conditions are supplied from one of the two lines.

Another important factor in the selection of regulating equipment is the severe short-circuit effects possible in a system of which the ultimate capacity of the present three generating stations will be approximately 500,000 kv-a.

The comparison made to determine upon the most satisfactory type of regulating equipment and the reasons for the selection of three-phase induction regulators are given. Data on the performance characteristics of the lines, with the induction regulators are included.

In the discussion of this problem of voltage and power factor control, certain conclusions of a more or less fundamental character are brought out.

THIS paper deals with a particular installation for control of voltage and power factor, made necessary by the interconnection of a large system, rather than a discussion of this question in a general way. An outline of this specific problem with its requirements, a discussion of the factors determining the selection of equipment, and a presentation and discussion of data on operating characteristics are included. This plan is adopted because it is thought that a paper of this sort will be of more value than one touching upon the subject in a more general way.

This interconnection is made by means of very short transmission lines and, therefore, does not involve any of the problems which go hand in hand with the use of long transmission lines, but is of particular interest on account of the exacting requirements for voltage and power factor control under various distributions of load, and the severe short-circuit effects encountered.

The Philadelphia Electric Company supplies Philadelphia, Pa., and surrounding territory with electrical energy mainly through three large steam generating tations, known as the Schuylkill, Delaware and Chester Stations, the present total capacity of which is approximately 275,000 kv-a. and the ultimate 500,000 kv-a. The growth of the demands for power in the district of which Chester, Pa., is a center necessitated the building of the Chester Station. With the completion about three years ago of this Station came the need for transmission lines connecting it with the Schuylkill Station in Philadelphia to permit of the most economical loading of these stations and make possible the use of minimum reserve generating capacity.

Two 66,000-volt lines, 14 miles long, of approximately 20,000 kv-a. capacity each, with step-up and step-down transformers arranged as shown in Fig. 1, are provided.

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

The transmission of 40,000 kv-a. for a distance of 14 miles would not in itself call for a line potential of 66,000 volts, but the possibility of future extension and interconnection with other systems made the use of a voltage as high as this desirable.

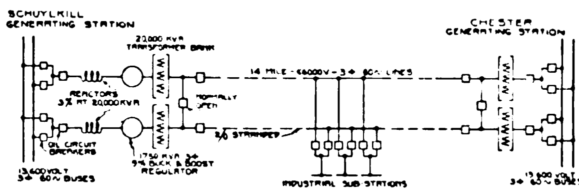


FIG. 1—SINGLE-LINE DIAGRAM OF SCHUYLKILL-CHESTER TRANSMISSION LINES

Disconnecting switches, instrument transformers, lightning arresters, etc. are omitted

The Delaware Station has direct cable ties with the Schuylkill Station, but has no tie lines connecting with the Chester Station.

THE NECESSITY FOR VOLTAGE AND POWER FACTOR CONTROL

The need for voltage and power factor regulating equipment on the Schuylkill-Chester lines is clearly

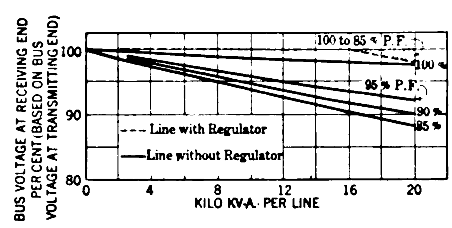


FIG. 2—CURVES SHOWING VARIATION, FOR SEVERAL DIFFERENT POWER FACTORS, OF VOLTAGE AT RECEIVING END OF LINE WITH THE KV-A. TRANSMITTED

brought out by the curves of Fig. 2, which show the inherent regulation of the lines, as shown by Fig. 1, except that the regulators are not included. It is obviously impossible to obtain satisfactory operation with the generating station bus voltage differing by

11.5 per cent, which is the figure for the transmission of 20,000 kv-a. per line at 85 per cent power factor. The curve for transmission at unity power factor indicates that 20,000 kv-a. can be transmitted over each line at that power factor with a voltage difference of only 2 per cent, which is entirely satisfactory. If this is done, however, there will be a certain amount of excess reactive kv-a. to be carried by the generating station to which the lines are supplying energy, as the power factor of the load is about 85 per cent; and this is, in some cases, impracticable to carry out, and uneconomical. This question of relative power factors of the various generating units will be discussed in detail in another part of this paper.

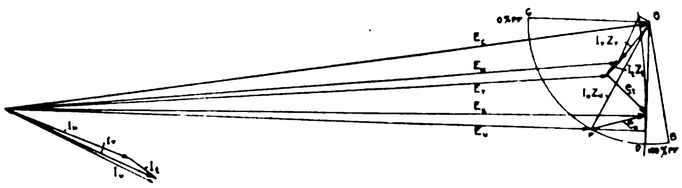


Fig. 3—Vector Diagram of Current and Voltage Relations of the Two 66,000-Volt Transmission Lines for Certain Assumed Loads

E_c —Chester Station bus voltage
E_H —Industrial consumer's voltage
E_s —Schuylkill Station bus voltage
E_u —Line voltage at regulator (untapped line)
E_T —Line voltage at regulator (tapped line)
e_u —Regulator voltage (untapped line)
e_t —Regulator voltage (tapped line)
I_u —Current in untapped line
I_T —Current in tapped line at Chester Station
I_H —Current taken by industrial consumers
I_t —Current in tapped line at Schuylkill Station
Z_u —Impedance of untapped line
Z_T —Impedance of tapped line—Chester Station to consumer
Z_t —Impedance of tapped line—consumer to Schuylkill Station

Regulation Requirements

An analysis of the problem brought out the following requirements for voltage and power factor control, which were important factors in determining the selection of equipment for this service.

The demand for large blocks of power, totaling about 15,000 kv-a. at about 90 per cent power factor, by three industrial consumers located adjacent to these lines necessitated their connection thereto. In order to meet all operating conditions, it was decided that regulating equipment must make possible the loading of both lines to rated capacity at either end, depending upon the direction of energy transfer, regardless of the size of the industrial load and whether it is split up between the two lines or all supplied from one line.

The vector diagram shown in Fig. 3 gives the voltage and current relations of these two lines under the assumed maximum load conditions given for point No. 2 of Fig. 9. Reference to this diagram will give an idea of the relative values of the impedance drops in the line supplying the industrial load and the line which runs straight through with no industrial load on it. To make such load conditions possible, it is evident that the two voltages e_t and e_u must be in series with the two lines in order to meet the bus voltage E_s, and the turbine governors adjusted for the desired kilowatt value. Further consideration of this question will show that as the industrial load diminishes or increases, or is split up between the two lines, the angle and magnitude of the two voltages e_t and e_u should change to keep the same power factor and voltage conditions. This would indicate that regulating equipment selected for this service should have to be of such character as to give a voltage of variable magnitude and phase angle.

The large ultimate generating capacity of the stations at each end of the lines will in the event of a short circuit at the bus deliver a maximum of 700,000 kv-a. The very high short-circuit effects encountered, combined with the necessity for the utmost reliability, led to a decision to install no regulating equipment but that of the most substantial and sturdy construction.

Comparison of Various Forms of Regulating Apparatus

Types of equipment considered for the installation in question include the synchronous condenser, the step-type regulator, the synchronous booster, and the three-phase induction regulator.

Synchronous condensers are not practicable for use in this instance because of the necessity for maintaining approximately equal bus voltages in both generating stations and for transmitting energy in both directions. The curves of Fig. 4 show clearly that at line power factors which give a voltage drop of permissible magnitude, the capacity of condensers required is excessive, resulting in a large investment and space requirement. As an example, if we assume the voltages at the ends of the lines differing by 2 per cent, it is found by referring to Fig. 4 that approximately 10,000 kv-a. condenser capacity is required at the ends of the line, thus necessitating a total capacity of 40,000 kv-a. The value of these condensers in reducing the amount of reactive kilovolt-amperes carried by the

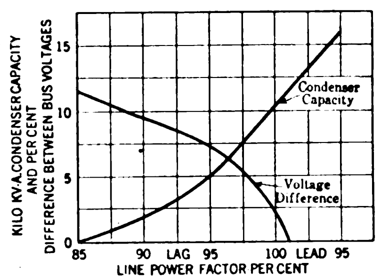


Fig. 4—Curves Showing Difference Between the Two Generating Station Bus Voltages When 20,000 Kv-a. is Transmitted Over the Lines at Various Power Factors, and the Condenser Capacity Required to Give These Power Factors When the Load Power Factor is 85 Per Cent

generators should not be overlooked, but in this instance it was not great enough to warrant their installation.

The step-type regulator which has been developed primarily for electric furnace and electrolytic work, consists essentially of a series transformer connected in the line and energized with voltages of various magnitudes from a special transformer supplied with taps and arranged with single-phase induction regulators, so that a gradual change in voltage is possible.

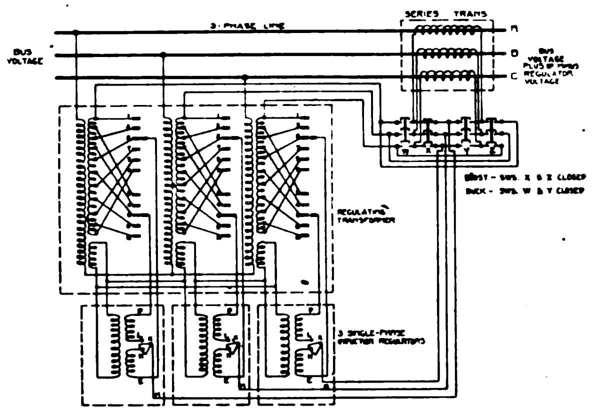


FIG. 5—DIAGRAM OF ELECTRICAL CONNECTIONS OF "STEP-TYPE" REGULATOR

Fig. 5 shows the elemental electrical connections of an equipment of this type for transmission lines regulation. The manner in which this apparatus functions is outlined in detail in Appendix A.

Among the advantages of this type of regulating equipment are that it can be built to withstand severe short circuits because the only apparatus in series in the lines are transformers, and it is slightly cheaper than other types of apparatus for the same service. The principal disadvantages are in the high-voltage sliding contacts which may give trouble and would be difficult to keep in condition, and the complication made necessary to secure the variable phase angle required to permit of loading the lines under different operating conditions.

The synchronous booster ordinarily does not give a variation of phase angle of its voltage; but it can be arranged so that the stator frame can be shifted at will through a certain angle, thus varying the phase angle of its voltage. When so equipped with a frame-shifting device, the synchronous booster gives more flexibility than the three-phase induction regulator because its voltage can be varied in both magnitude and phase angle, while that of the regulator can be varied in phase angle only.

In respect to this application, the induction regulator has many desirable features as compared with the synchronous condenser and the step-type regulator, and appeared to be superior to the synchronous booster. The problem, therefore, resolved itself to a great extent into an exact comparison of the induction regulator with the synchronous booster, equipped with a frame-shifting device. An analysis was therefore made of the operating characteristics of the transmission system which indicated that induction regulators giving a constant voltage of 9 per cent with a variable phase angle would permit of the desired conditions of load, and they were selected for this service in consideration of their advantages as compared with synchronous boosters, listed below:

1. More sturdy construction.
2. Ability to withstand greater short-circuit stresses.
3. Greater simplicity of operation.
4. Higher efficiency.
5. Smaller first cost.
6. Suitability for outdoor installation which greatly facilitated the arrangement of equipment.
7. Is not a "rotating" machine.
8. Less inspection and maintenance required.

It is true that the synchronous booster with a frame-shifting device permits of more exact control of the lines but the resulting gain is slight and is not comparable with the advantages of the induction regulator set forth above.

DESCRIPTION OF THE INDUCTION REGULATOR

Two 1750-kv-a., three-phase, 60-cycle, oil-insulated, water-cooled, motor-operated induction regulators of Westinghouse manufacture, designed to give 9 per

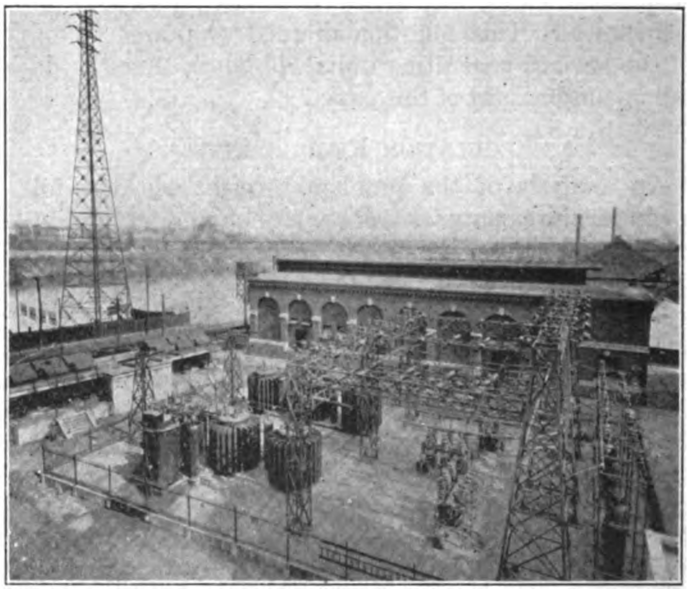


FIG. 6—GENERAL VIEW OF THE OUTDOOR SUBSTATION IN WHICH THE REGULATORS ARE INSTALLED

cent buck and boost on a 13,600-volt circuit, were installed in the Philadelphia outdoor substation, a general view of which is included in Fig. 6.

Fig. 7 is a close-up view of one of the regulators, showing breather and temperature indicating equipment. Arrangement for hand operation is provided but is not shown in the illustration. The height of

the regulator is 14 ft. 10 in.; the diameter 6 ft. 3 in., and the weight 56,000 lb. when filled with oil.

The regulators can easily be disconnected from the lines if desired when they are not "working" by unbolting the cable connection of each phase at the point *A* and reclamping at the point *B*, from which the cable for normal operation has been removed. This change in connection can be carried out in a very short length of time.

When operating at rated load, the losses of each regulator are 40 kw. and 20 gallons of cooling water per minute are required.

The stator and rotor coils are braced and insulated with A. I. E. E. class B insulation, in accordance with the standard turbo-generator practise.

The regulators are guaranteed to withstand successfully short-circuit currents as great as fifteen times the rated load value. Special stretch bolts are provided in the operating mechanism of the regulator so that in the event of an unusually severe short circuit, they will give way, thus preventing serious damage to the regulator.

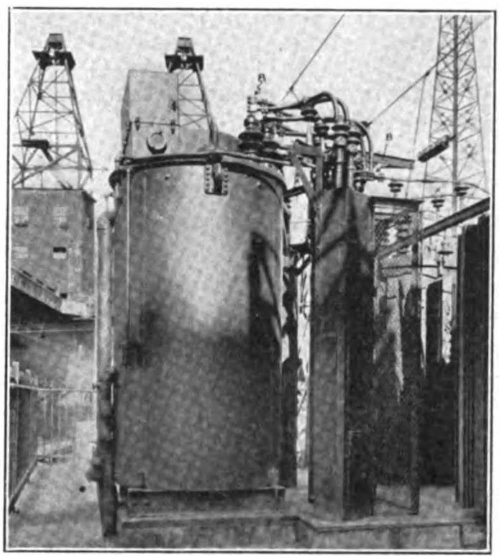


Fig. 7—Close-up View of One of the 1750-Kv-a. Induction Regulators

Reactors giving 3 per cent drop at rated circuit kilovolt-amperes are installed on the Schuylkill Station end of the line to limit short-circuit currents to a safe value in order to amply protect the equipment installed thereon.

The switches controlling the regulator operating motors are located on the generating station control panels for these lines, to facilitate operation.

To give further ease of operation, each regulator is provided with a position indicator located on the instrument panel of the line to indicate the angular position of the regulator voltage. This indicator consists essentially of a special 360 deg. power factor indicator; one set of potential coils is connected to the line potential transformers, and the other coil to a potential transformer connected across a secondary winding of the regulator. The regulator has four poles and the pointer of the indicator consequently makes two revolutions to one revolution of the regulator rotor. The markings of the dial of the instrument are shown by Fig. 8 and are arranged so that the operator can readily secure the desired load conditions. The pointer is usually in the half of the scale which has the words *to Chester* printed on it where transmitting energy to Chester, and is in the part of the scale marked *to Philadelphia* when transmitting in that direction.

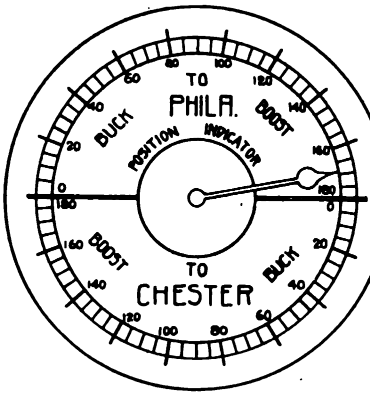


Fig. 8—Diagram Showing Marking of Position Indicator Dial

Discussion of Transmission Characteristics

The analysis of the operating performance of the transmission system was made by means of a circle diagram similar to the one shown in Fig. 9, developed to meet the need for some means for readily determining upon the load conditions which should be obtained on these lines under various operating conditions. The principles involved in the construction

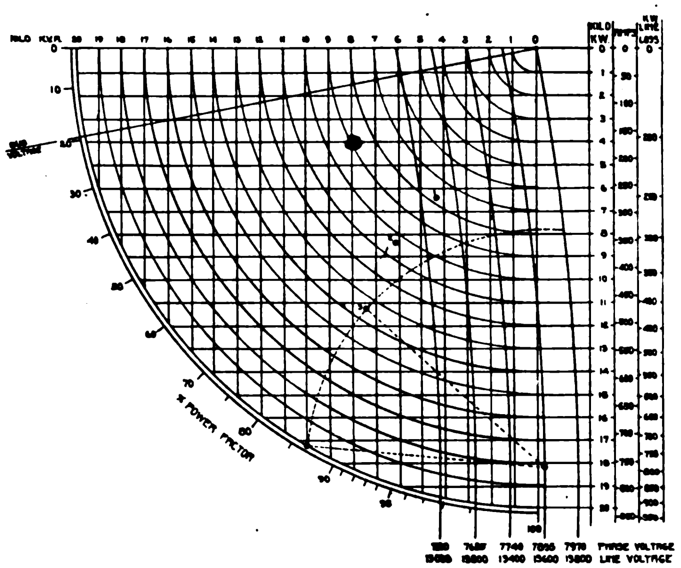


Fig. 9—Circle Diagram of Performance Characteristics of the Transmission Lines

of this diagram and the method of using it are outlined in Appendix B.

The curves given in Fig. 10 are plotted with readings taken from this diagram and show the transmission of energy from Chester to Philadelphia over the untapped line (no industrial consumers connected), for different amounts of kilovolt-amperes at 90 per cent power factor, furnished to the consumers from the tapped line which is supplied with 20,000 kv-a. at 85 per cent power factor at the Chester Station. Curves *A*, *B*, *C* and *D* show the kilovolt-amperes which can be transmitted at 85 per cent power factor (based on Chester bus voltage) over the untapped line with respectively, zero, one, two and three per cent, difference between the bus voltages of the Chester and Schuylkill generating stations, when the regulators are in one of two possible combinations of positions. Curves *A* and *B* do not extend to the 20,000 kv-a. point as do the others because it is impossible to obtain the load conditions necessary for this with zero and one per cent difference between bus voltages.

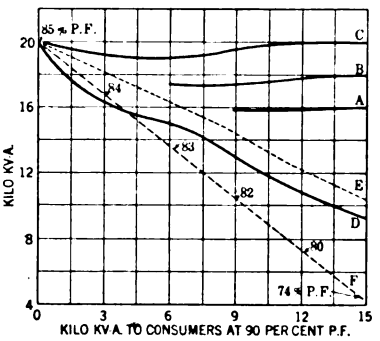


Fig. 10—Curves Showing the Amount of Kv-a. Which Can Be Transmitted From Chester to Philadelphia Under Various Conditions

Curve *F* (Fig. 10) shows the kilovolt-amperes transmitted over the tapped line through to the Schuylkill station and has marked along it at different points, the power factor at that particular load condition.

If the regulators are operated in the other possible combination of positions so that the line will receive kilovolt-amperes from the Chester Station at 85 per cent power factor, the kilovolt-amperes which can be transmitted with bus voltages equal or differing by as much as three per cent are shown by Curve *E*.

The second combination of regulator positions does not in most cases permit of as high kilovolt-ampere loads being carried as does the first and is, therefore, in general not desirable.

The two possible regulator positions referred to above are shown in Fig. 11 for an assumed load, of current I_l causing an impedance drop e_3. The regulator voltage can take either the position e_1 or e_2 to meet the receiving bus voltage E_1 provided the stations are not tied together through other lines. Figs. 10 and 12 indicate the desirability of one of these regulator positions as compared with the other.

It would appear as though regulator position e_1 is the better of the two, insofar as line power factor is concerned, because it apparently counteracts to a great extent the effect of the line reactance in producing reactive kilovolt-amperes which the generators must carry. This is not true, however, as the ratio current of the regulator when combined with the load current gives a total line current having an angle between it and the load current equal to the angular displacement of the line voltage caused by the regulator voltage, with the result that there is no change in line power

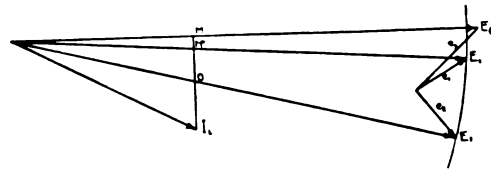


Fig. 11—Vector Diagram Showing the Two Possible Regulator Voltage Positions for an Assumed Load

factor made thereby. There is, of course, a small change of angle brought about by the exciting current and impedance of the regulator.

Fig. 12 shows the various kilovolt-ampere values that can be carried on the untapped line with the regulators in all the possible positions when the tapped line is carrying 20,000 kv-a. at 85 per cent power factor at the Chester Station and is supplying the industrial consumers with 15,000 kv-a. at 90 per cent power factor. Inspection of these curves will reveal the fact that with the one combination (Curve *B*) of regulator positions

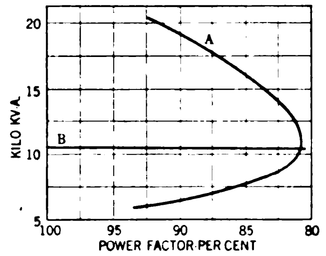


Fig. 12—Curves Showing the Various Load Conditions Possible on the Untapped Line When Transmitting from Chester to Philadelphia With Equal Generating Station Bus Voltages

it is practically impossible to vary the kilovolt-amperes, but the power factor can be varied. The other combination (Curve *A*) permits of considerable variation of both power factor and kilovolt-amperes and is the more desirable one.

Fig. 2 includes curves showing the transmission of kilovolt-amperes over the lines using the regulators, when there is no industrial load supplied from the mid-point of the line.

One of the limitations of the control of voltage and power factor is in the maximum voltage which can safely be impressed on the transformers at each end of the lines. Owing to the position of the regulators

relative to the transformers, this limitation is of consequence only when transmitting energy to Chester from Philadelphia.

Operating experience with these regulators for control of voltage and power factor has been very satisfactory and verifies the results of the analysis made to determine upon the capacity and characteristics of the regulating equipment. There are no rapid fluctuations of load on these lines under normal conditions and, therefore, no difficulty is experienced in maintaining the desired power factors. Some apprehension was felt at first as to the form of instructions which would enable the operators to readily load the lines as desired, but it was found that the position indicators used with the other instruments on the lines made satisfactory operation possible.

The lines connecting generating stations may be used under many conditions to increase the combined economy of these stations. The exact increase in economy made possible by securing more efficient loading of the generating units under various operating conditions is rather difficult to determine, as there are

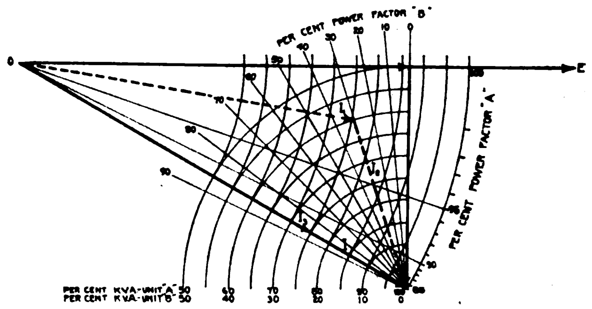


FIG. 13—GRAPHICAL REPRESENTATION OF THE INCREASE OF GENERATING CAPACITY REQUIRED BY OPERATION OF UNITS AT UNEQUAL POWER FACTORS

many factors involved. An instance where higher efficiency may be obtained is the case where the units of one station are lightly loaded and those of a second station heavily loaded, and by the use of the tie lines the load may be equalized so that all of the generators will operate at or near the most economical point, which in most cases is in the neighborhood of 75 per cent of the rated capacity. Or, again, we may have two stations in which the units are lightly loaded, in which case the proper transfer of load over the tie lines may make possible the shutting down of one machine and the operation of the remaining units in both stations at a higher efficiency. If, on the other hand, the generators in both stations are heavily loaded, an available spare machine could be started and the load equalized over the tie lines so that all of the machines would operate at a more efficient point.

In cases where there are generating units or stations differing by a considerable margin in economy, it is often found desirable to operate the efficient units at or near unity power factor, and carry the lagging reactive kilovolt-ampere on the less efficient machines. Where there is a large modern generating station with units of higher efficiency in it than in the older stations, it is customary to keep the most efficient station as near fully loaded as possible, at or near unity power factor. This arrangement requires, however, that the combined kilovolt-ampere generating capacity in use be greater than that of the load, the amount depending upon the difference in the power factors of the generators involved. This will be evident by referring to Fig. 13. To illustrate the point in mind, let us assume that an efficient station which will carry 75 per cent of the kilovolt-ampere load, is available. This station, which supplies the current I_3, will be called unit A and the scales so designated should be used to read its kilovolt-ampere and power factor. Scales marked unit B should be used in the same way for the less efficient unit. Reference to the diagram will show that when both stations are supplying current (I_3 and I) at the load power factor, the total kilovolt-ampere generating capacity is a minimum and is equal to 75 per cent (scale A) plus 25 per cent (scale B) or one hundred per cent of the load kilovolt-ampere.

If, however, unit A supplies the current I at approximately 99 per cent power factor, it will supply 75 per cent of the load kilovolt-amperes and unit B which supplies the current I_2 is operating at power factor of about 30 per cent and supplies kilovolt-amperes equal to 40 per cent of the load; the total kilovolt-ampere generating capacity under this condition is 115 per cent of the load kilovolt-amperes.

The excess kilovolt-amperes required increases as the power factor of unit A approaches unity, and that of the unit B approaches zero or vice versa, and reaches a maximum of 37 per cent at unity and zero power factor, respectively, with a load power factor of 85 per cent. When the load power factor is higher, this additional generating capacity required to operate at unequal generator power factors becomes smaller.

The discussion given above relative to operation of units to obtain maximum economy applies either to individual units in a station or to several stations of groups of generating units. It is obviously only directly concerned with the operation of tie lines when two or more stations are involved.

CONCLUSIONS

Interconnection of any particular system presents problems which must be solved individually by making a thorough analysis, including consideration of all pertinent features. The use of induction regulators for the control of voltage and power factor in the instance discussed in this paper does not indicate in general that this is the best method of handling the problem.

Summarizing, it could be said that equipment selected for the control of transmission lines should meet the following conditions which are more or less fundamental:

The equipment must permit of the desired transmission of energy at suitable power factor under all operating conditions.

Apparatus of sturdy construction which will give the greatest degree of reliability is absolutely essential, considering the great importance of this service. There is always a possibility that the breakdown of any equipment of generating station tie lines may cause disturbances throughout the system, which may lead to serious consequences. An installation which will require considerable inspection and maintenance is to be avoided.

Regulating equipment which does not permit of ease and simplicity of operation is, as a rule, undesirable. If the operation is complicated, errors are more likely to occur which sometimes lead to serious trouble.

The initial cost of regulating equipment and the cost of operation, including maintenance, are important factors and must be given due consideration.

It is hoped that this paper, although it is a discussion of a specific problem, brings out information of a general character which will be of value to those facing the problem of voltage and power factor control of interconnected systems.

The author wishes to express his appreciation of the helpful assistance of Mr. Frank R. Ford in the preparation of this paper.

APPENDIX A

The Step-Type Regulator

The manner in which the "step-type" regulator functions to give a gradual change of voltage can be most readily understood by following it through one step of the operation.

The voltage induced in each of the regulator coils *N-E* and *L-D* (Fig. 5) is equal to one-half of that between adjacent taps of the regulating transformer. If we assume switch *K* (Fig. 5) closed on contact *N* and the lead *E* of the regulator secondary coil connected to contact 5, then the voltage of the regulating transformer between leads 1 and 5 is impressed on the series transformer when the regulator is in the neutral position. As the regulator is turned in the direction so that the voltage of the coil *N-E* adds to the voltage between taps 1 and 5, the point is reached when the voltage impressed on the series transformer has been increased by the maximum regulator voltage, and the lead *M* is half-way between taps 5 and 6 in potential. As the voltages of coils *N-E* and *L-D* are exactly equal and opposite, the lead *L* is at the same potential as lead *M* and switch *K* is swung from contact *N* to *L*, the brush of lead *D* having just moved on to contact 6. This impresses the voltage from taps 1 and 6, minus that of the regulator winding *D-L*, on the series transformer, thus giving a voltage midway between taps 5 and 6. As the rotation of the regulator is continued, the voltage of the winding *D-L* decreases until the voltage of the regulator is zero and the impressed voltage is equal to that between taps 1 and 6. Further rotation increases the voltage of the induction regulator until the potential of lead *M* is half-way between taps 6 and 7, when the change is made to the regulator coil *N-E*, the selector switch having moved from tap 5 to tap 7 while the rotation of the regulator has taken place. The continuation of this process gives the desired change in voltage up to and including the capacity of the equipment.

The various switches and inductance regulators referred to above are mechanically interlocked so that they function in synchronism as desired. To change from buck to boost or vice versa it is necessary to operate the switches provided for that purpose and so designated on the diagram. It is possible to provide an equipment of this sort with switches so that the series tranformers can be short-circuited when they are neither bucking or boosting, so that they can be disconnected from the line even when it is carrying load.

APPENDIX B

Circle Diagram of the Transmission Lines

The construction of this circle diagram can be readily understood by referring to the vector diagram of Fig. 3, which shows voltage and current relations on the two 66,000-volt lines under certain assumed load conditions. The industrial load is assumed for the sake of simplicity to be grouped at the mid-point of the line. The following considerations refer to whichever line has no industrial load on it or, of course, to both lines if we assume no industrial load.

The length of the vector (Fig. 3) representing the impedance drop bears a definite relation at fixed bus voltage to the kilovolt-amperes transmitted over the line, and a scale placed on the diagram which will read the length of this vector *O-F* in any position can be marked to read kilovolt-amperes transmitted over the line.

A scale placed on the diagram so as to read the projection of the impedance vector on the line *O-D* can be marked to read kilowatts transmitted, and if desired, the reactive kilovolt-amperes can be read on the scale which indicates length of the projection of this same vector on a line 90 deg. from the one reading the kilowatts.

There is also a definite angular position of the impedance drop vector for each line power factor. At unity power factor it will take the position *O-D*; *O-B* is perpendicular to E_c and the ratio of *D-B* to *O-B* is equal to the ratio of the resistance of the line to its reactance. At zero power factor, the vector will swing around 90 deg. to the position *O-G*. The arc *D-F-G* can obviously be marked to read power factor of the line.

The circle diagram of Fig. 9 is based on the principles

outlined above, omitting most of the vectors of Fig. 3 for the sake of simplicity and adding the necessary scales each with a series of guide lines to facilitate reading the different values. In addition to the scales referred to above, there have been added, one for reading the amperes at 13,600 volts (as this was of more practical value than the amperes at 66,000 volts) and another for reading kilowatts lost in the transmission system. The kilowatt loss includes in addition to the copper loss in all parts of the circuit, the core losses of the regulator and transformers. These scales are based on a bus voltage of 13,800 volts and apply only to the line which is not carrying an industrial load.

It will be found that a circle, drawn on a piece of celluloid, representing the voltage of the regulator to scale, will be of material assistance in taking readings from the circle diagram. To take a set of readings, the celluloid is placed on the diagram so that some part of the circle coincides with the point which defines the end of the impedance drop vector on one line and the center of this same circle on the arc representing the bus voltage, which it is desired to have at the receiving end of the lines. The load conditions which it is impossible to obtain on the other line can be read at any point on the regulator circle, as desired.

In order to illustrate the method of using this diagram, two sets of readings of load on the untapped line will be taken for the load conditions shown by point No. 3 for the tapped line. If it is decided that the Schuylkill bus voltage should be 13,600 volts, then the regulator in the tapped line should be in the position indicated by the dotted line connecting with point 3. The point of intersection of this regulator voltage with the bus voltage line is the center of the regulator circle for the untapped line, and its position has been indicated on the diagram. The intersection of the regulator arc with the 20,000 kv-a. arc is the point for which readings will be taken to determine the conditions under which 20,000 kv-a. can be transmitted. The readings are: 17,200 kw. 87 per cent power factor, 10,000 reactive kv-a., 840 amperes, and 925 kw. loss. If it is desired to transmit energy from the Chester Station at 85 per cent power factor, the intersection of the regulator arc with a line from the center of the diagram to the 85 per cent power factor mark, is the point determining the readings, which are as follows: 18,000 kv-a., 15,200 kw., 9600 reactive kv-a., 750 amperes and 775 kw. loss. All readings obtained are based on a voltage of 13,800 volts at Chester, and if it is desired to operate this station at any other voltage the proper corrections must be made.

If it is desired to transmit energy over these lines from the Schuylkill Station to Chester, different points will have to be calculated and plotted on the diagram, as the impedance from the Schuylkill Station to the consumers is not the same as from the Chester Station to the consumers. If there is no load supplied to the consumers, the analysis of performance characteristics is somewhat simplified as the load condition which can be obtained on any line can be read without plotting points, by simply making use of the proper scales and the regulator circle.

It must be kept in mind that the values read from this diagram are approximate but are satisfactory for the purpose of making studies of line performance.

CITIZENS MILITARY TRAINING CAMPS

During the coming summer the War Department plans to hold within each Corps area a Citizen's Military Training Camp, to which all men between the ages of 16 and 35, of good intelligence character and physical condition may apply for admission. The camps are intended primarily for men of little or no military training in the hope that they will associate themselves with the National Guard or the Reserve. They will be maintained for a period of four weeks beginning not earlier than July 15th and not later than August 10th. The Government will pay for each man in training full expenses of transportation, subsistence, quarters, uniforms, equipment, laundry service, medical and dental care. The program of training calls for the initiation of young men into the conditions of camp life and the elementary duties of the soldier; stress will be laid on physical development through out-of-door games and sports; expert and individual medical attention will aim at the removal of minor bodily defects; social recreation will be afforded through all kinds of lectures, vaudeville, moving pictures, amateur and dramatic musical entertainment; on appropriate occasions voluntary religious exercises for men of all faiths.

The Military training Camps Association, 210 Mallers Bldg., Chicago, will send enrollment blanks to all applicants.

DEVELOPMENT IN NEW ZEALAND

There was an active interest taken in the development of hydroelectric sites by the New Zealand Government and individual companies, municipalities, and boroughs throughout the Dominion during 1920, with the result that plans were prepared for the development and distribution of a large amount of hydroelectric current for lighting and power purposes. The Government made good progress during the year in carrying out this general development scheme, covering both the North and South Islands. Government appropriations for hydroelectric development for the fiscal year ending with March 31, 1921, amounted to $3,224,055.

Modern Production of Suspension Insulators

BY EDWIN H. FRITZ

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AND

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Westinghouse Electric & Mfg. Co.

This paper pictures the progress made during the past few years in the production of electrical porcelain. The information covers: First: The engineering and works organization. Second: The manufacture. Third: Design and test.

THE DEVELOPMENT of transmission line networks has progressed even more rapidly than most of the pioneers in transmission engineering anticipated. No doubt, the development has been materially affected by the increased cost of fuel, which has encouraged the engineers to develop available water power sites. Perhaps, one of the most influential factors has been the necessity of irrigating the fertile lands of the Pacific Coast States. Electricity from water power sources can be generated and transmitted to the farming districts and can be economically employed to pump water, to heat the houses, and to operate the household appliances.

The quality of electrical porcelain, although sufficient to properly insulate low-tension lines, proved entirely unsatisfactory when it became necessary to increase the transmission line voltages. The first thought of the engineer was to emphasize the mechanical strength, but in so doing, he sacrificed other characteristics. He believed the insulators should withstand handling, impact blows from rifle shooting, etc. He believed suspension insulators must be mechanically strong to prevent dropping the line in service.

There are numerous reasons why the quality of electrical porcelain did not keep pace with the progress in transmission engineering.

First: There were few transmission networks when electrical porcelain was first applied to high voltages.

Second: The demand for electrical porcelain was extremely variable. When a transmission project was under consideration, it was necessary to supply a large number of insulators in a short time. After the material for this project was manufactured and supplied, the manufacturer could not keep a continuous production of high-tension electrical porcelain in his factory. He must again manufacture low-voltage insulators and dry process material such as knobs, tubes, cleats, etc.

Third: The type of labor from which the manufacturer drew his supply had never been trained to appreciate the advantages that can be derived from labor saving devices. They had been very adverse to accepting any new type of machinery, perhaps, more so than the usual workmen.

The most regrettable and fundamental reason of the slow development of electrical porcelain has been the lack of cooperation between the ceramic and electrical engineers. The ceramic engineer was occupied with manufacturing problems only. The electrical engineer, on the other hand, was usually a consulting engineer because the transmission company itself could not afford to assign an electrical engineer to the application of electrical porcelain. The design recommended by him would incorporate his ideas and opinions. He would probably not consult with the ceramic engineer to determine the limitations in manufacture. The varied line of designs which every insulator company carried a few years ago is indicative of this condition.

Engineering Organization

The increased demand for electrical porcelain has enabled the manufacturer to command men of greater engineering ability. These men have sufficient training to appreciate the advantages that are gained by close contact between the manufacturer, the engineer, and the consumer. The organization of the modern electrical porcelain manufacturer is built on close cooperation between engineers who have supervision of the works and the application of the finished product.

The ceramic research laboratory operated as a separate department, is of vital importance. Its function is to investigate the present commercial raw materials; new sources of supply; the proportioning of ingredients; the glaze, etc. This laboratory has complete equipment, a portion of which constitutes a miniature clay working plant. This enables the engineer in charge of the laboratory to produce experimental bodies and determine such properties as dielectric strength, mechanical strength, both tensile and impact, resistance to temperature changes, firing range, and shrinkage. Fig. 1 will give a general idea of the completeness of this laboratory.

In connection with this, the proper selection of materials is of extreme importance. For example, we find different grades of clays in the same deposit, some of which will give considerably better results than others which may be only a few feet removed from them in the same strata. The ball clays which are now used contain a considerable amount of lignite and organic matter. This type of clay vitrifies at a much lower temperature than some of the cleaner ball clays and at the same time is a very tough and strong material, such as is necessary to overcome the severe stresses

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

which are encountered in manufacturing the complex insulator shapes. The low vitrification temperature is especially desirable because it assists the feldspar in the vitrification of the product and insures a greater firing range with less danger of underfired or overfired material.

English ball clay has always satisfied these characteristics in the past to the greatest possible extent. Laboratory investigations in recent years have discovered some promising American clays and at the present time experiments are being made on some clays in an undeveloped field in this country which seem to be even superior to the English clays. The laboratory is, therefore, continually investigating new materials and with the continual progress that has been made, it would not be too optimistic to predict that we may at some time find materials which will improve the present product.

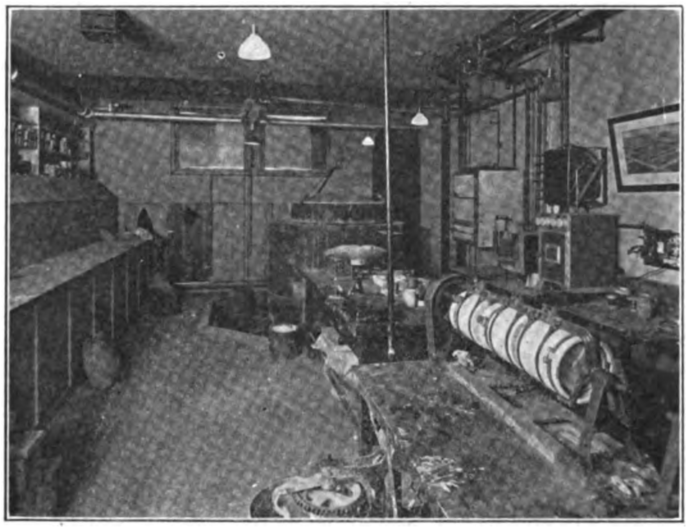

FIG. 1—CERAMIC RESEARCH LABORATORY—GENERAL VIEW

The proportioning of feldspar, flint and clay has been given very careful consideration in the research laboratories. The present commercial body is based on the results of this work. It is possible to obtain porcelain bodies from these materials in which certain characteristics predominate. However, since the application of electrical porcelain is very wide, it is necessary to sacrifice high mechanical strength or very high dielectric strength in order to obtain a body which will be satisfactory in all applications.[1]

A second ceramic laboratory is maintained at the works; the function of this department being to properly apply information obtained in the research laboratory to the commercial product and to see that all departments of the works function properly, *i. e.*, that the proportioning and mixing of the ingredients is uniformly performed; that the material is properly prepared for the manufacturing processes; that the speed of the machine in forming and trimm ng the ware is correct; that the firing conditions are uniform, etc. There is very close contact at all times between the two departments and by the continual exchange of ideas each is informed of the other's activities.

One of the most important activities of the works department is the testing of all raw materials as they are received, in order to insure uniformity of the material and the finished product. Feldspar has become so variable in recent years that the old method of assuming that the feldspar will always be uniform in quality is now a hazard. Each shipment must be tested especially in regard to fusibility, for it is this property which has become most variable. A sample is obtained from the car as soon as it is received; the flux value established and if not in accordance with purchasing specifications, it is rejected before coming in contact with any of the material in the bins. The remaining materials are tested in a similar manner. Other routine tests are the determination of the moisture content and non-clay substance in the clays from day to day so that this variable can be adjusted for on the scales and consequent uniform mixture produced.

The electrical engineering department functions in a similar manner. The consulting staff of the company is available when problems arise covering the design and application of the finished product. The Engineerign Department at the works supervise routine testing and the application to the product of suggestions that are made by the consulting staff. It is also a function of the Engineering Department at the works to give careful thought to any suggestions from the field which are based on the inherent design of the product.

MANUFACTURE

The modern electrical porcelain works are the result of the changed conditions and indicate what closer cooperation and a more scientific organization have accomplished. This is most forcibly illustrated in the slip house where the materials are mixed. This department was formerly found in the most dilapidated part of the works and gave an appearance which was repulsive to the intelligent class of workmen. In other words, it was located and operated under conditions which indicated that it was an unimportant department.

Today we find the reverse of these conditions. This department is now considered one of the most important if not the most important, part of the works and the general design and operating conditions are carried out accordingly. It contains the latest type of machinery, with special attention given to labor saving devices in order to make the processes more mechanical and eliminate the human factor wherever possible, with resultant greater uniformity. The department is well lighted and presents a sanitary appearance which is in keeping with the kind of work which is carried on.

The raw materials upon arrival after tests have been

1. "Experimental Investigation of Porcelain Mixes," G. I. Gilchrest and T. A. Klinefelter, *The Electric Journal*, March 1918, p. 77.

completed are unloaded in an efficient manner by means of suitable conveying equipment and stored in large bins to prevent contamination with undesirable substances which are carried about in the air in industrial centers. (Figs. 2 and 3.) These bins are directly adjacent to the mixing department and the same conveying equipment can be used to bring the material

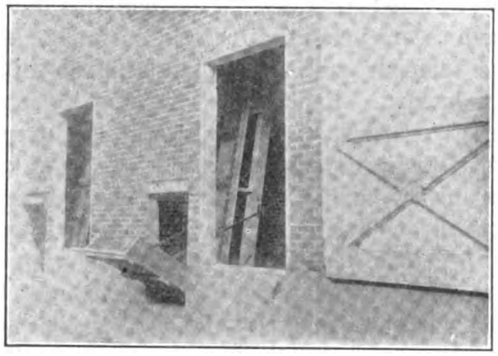

FIG. 2—EQUIPMENT TO HANDLE MATERIAL FROM CARS

into a location where it can be conveniently used in the process. (Fig. 4.) The materials are weighed with the minimum amount of manual labor and in such a way that the workmen cannot easily make an error of any consequence. The apparatus is built compactly so that the little transportation which is necessary is performed mechanically. (Figs. 5 and 6.)

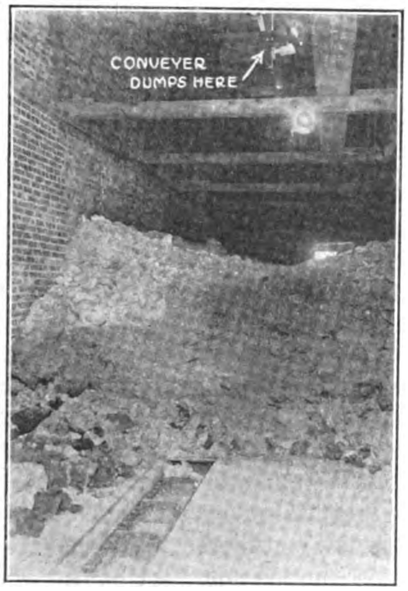

FIG. 3—MATERIAL STORAGE BIN

The feldspar and flint which were formerly mixed together with the clays in the blungers are now first ground in ball mills in the wet state sufficiently to produce a fineness which has been found to be necessary and which cannot be obtained in the dry state which is the means employed by the producers. (Fig. 7). The cost is large, but the resu ts that are obtained more than repay the manufacturer for this extra operation. The finer structure of the feldspar and flint gives a better mechanical mixture which makes these materials more active in their properties and effects a better performance of the body throughout the manufacturing process, especially in the firing operation. Vitrification begins at a lower temperature and a longer

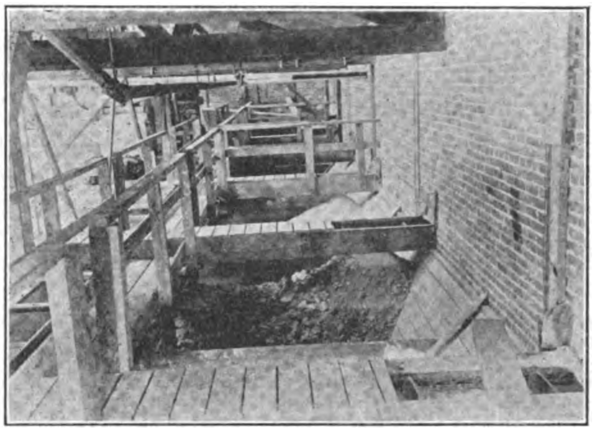

FIG. 4—MATERIAL BINS FOR DAILY CONSUMPTION

firing range is, therefore, obtained, or in other words, greater variation of temperature in the kilns is permissible without detrimental effect on the fired product. It is obvious that the danger of underfired ware is, therefore, materially lessened and on account of the improved methods of kiln firing, an underfired piece of electrical porcelain in the factory is indeed rare.

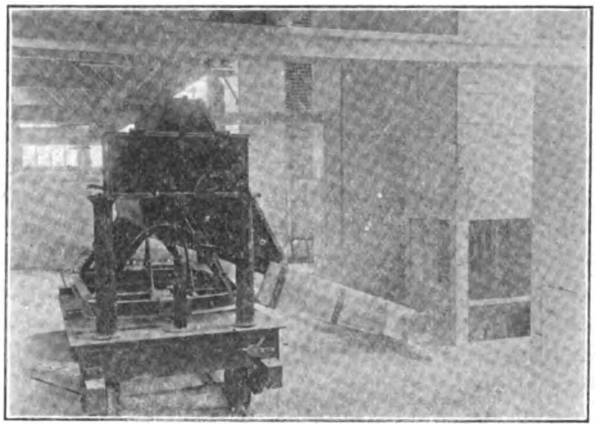

FIG. 5—METHOD OF TRANSPORTING MATERIAL TO MIXERS

Porcelain made from ball milled feldspar and flint is more homogeneous in structure and gives a very smooth fracture. It has a higher dielectric and mechanical strength, although in the case of the latter there is a limit to the fineness which will increase the value of this property. In general it has been very definitely proved that this operation is one of the greatest progressive steps in recent manufacturing developments.

While these materials are being milled the clays are mixed in blungers. The design of the blunger has been changed in recent years and machines are now on the market which are much more efficient and rapid in their performance. Complete slaking of the clays is assured in this type of mill, so that lumps of unmixed clay are not found in the blunger when it is discharged, with consequent variation of the mixture. This has been

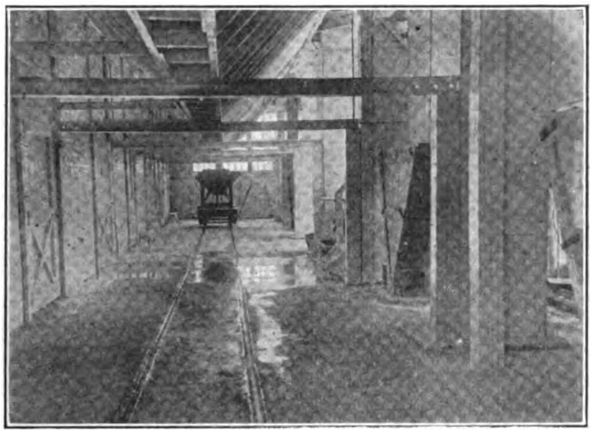

Fig. 6—Material Proportioning Equipment

accomplished by means of double rotating mixers which prevent any centrifugal force action and consequent collection of the particles at the edge of the tank which is so commonly found in the old type of blungers. Fig. 8). The feldspar and flint after being milled are added to this blunged clay slip and the entire mixture is then blunged sufficiently to produce as perfect a mechanical mixture as is possible.

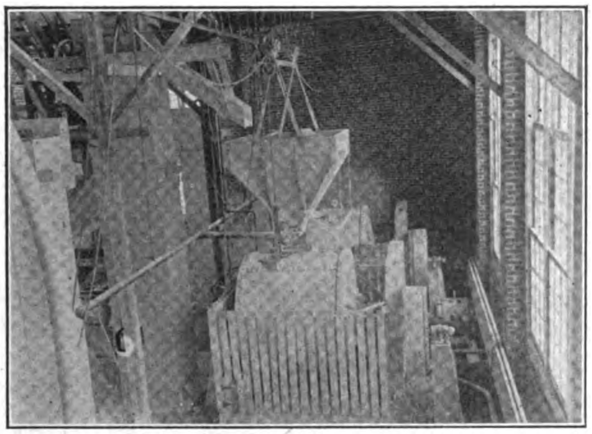

Fig. 7—General View of Ball Mills

The amount of water which is added to the clay flint and feldspar in the blungers and ball mills is carefully controlled by means of self-regulating water tanks above these machines. The amount of water in each tank is set from day to day in order to make proper adjustment of the water contained in the materials themselves. At the same time the water is heated to the proper temperature and kept constant by means of automatic temperature regulators. In this way the liquid in the ball mills and the blungers is always of the same density and temperature which is essential in pumping uniform filter cakes and in keeping the plastic clay body at the proper temperature. (Fig. 9).

The clay slip is passed over a double set of lawns, the first lawn being of a coarser mesh than the second.

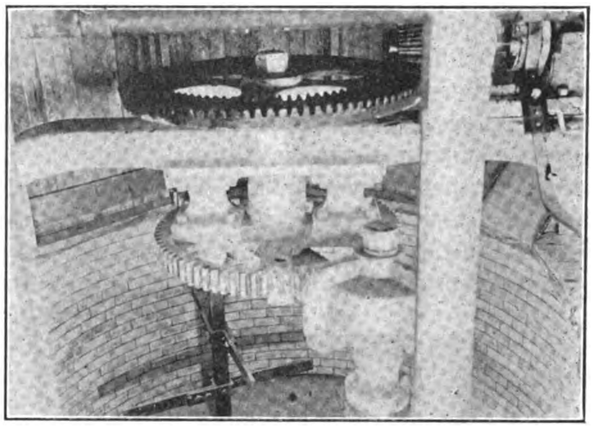

Fig. 8—View of Blunger Detail

This distributes the amount of residue on each lawn and lessens the danger of breaking the lawn and consequent passing through of coarse materials. After screening, the material accumulates in cisterns, which are now built of considerable size and number. The object in view is to provide storage for the clay slip after it has completely passed through the mixing

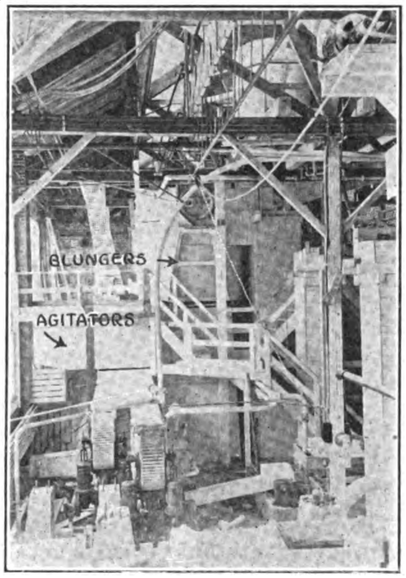

Fig. 9—General View of Section of Slip House

process where the air which is contained can be eliminated, giving a more homogeneous clay slip.

The pumps which force the material from the cisterns to the filter presses are designed to preserve the uniformity of the clay slip. The pumping action of the piston is now transmitted upon a diaphragm in order to isolate the clay slip from the pumping action.

Mixing of air in the slip at this point is, therefore, impossible and at the same time it does not get in contact with the oil in the cylinders. If the air is removed in the cisterns the filter cakes which will be produced at the press will be solid and contain no blebs of any kind. Furthermore, the pumps will not produce a higher pressure than what they are set for, so that the filter cakes are always uniform in water content and working qualities.

With such filter cakes the beneficial effect of aging is largely reduced and it has actually come to a point where equal results can be obtained from the manufacture of insulators from clay directly from the filter presses. Furthermore, ball clays have already passed through considerable natural aging and weathering conditions, and since they compose the major part of the clay content, the body is not noticeably improved

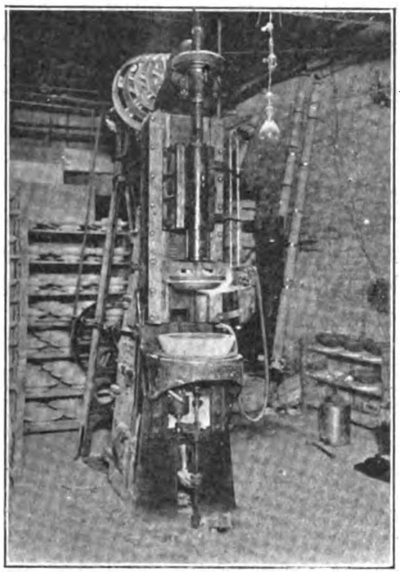

Fig. 10—Forming Machine

by a small amount of artificial aging. For this reason, aging would have to extend over a period of at least one month before any noticeable results would be obtained in the product and this, of course, necessitates a storage capacity which is not commercial in this country.

In pugmilling the material in preparation for the moulding process, the more modern and scientific methods of mixing have overcome many of the troubles which formerly were traced to the pugmill. It is now much simpler to produce a satisfactory material from the pugmill and with the improvements in this machine which have been obtained, the ever-present trouble with laminations has been largely overcome. If the material leaves the pugmill free of laminations and with no air contained, the success of the moulding of the insulators is practically assured.

In forming the insulators machine operations are used entirely. This method has proved to be superior to the jiggering process, because of the greater pressure which is obtainable and the elimination of the human factor with the consequent possibility of a non-uniform product. A greater production can be obtained from the machines with an improvement in quality. (Fig. 10.)

By means of modern conditioning dryers, the insulators can be rapidly and uniformly dried to the stage where they can be removed from the moulds without distortion. (Fig. 11.) They are then ready

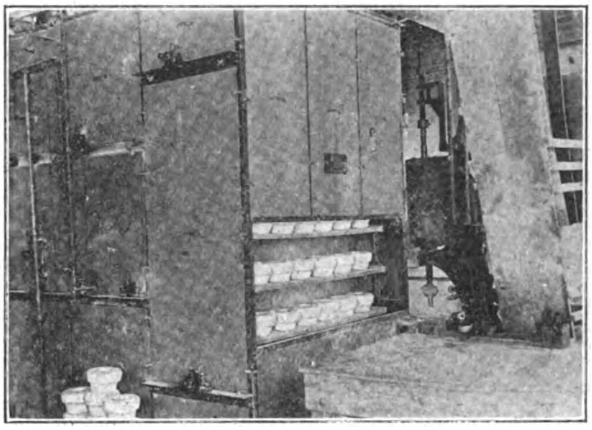

Fig. 11—Conditioning Dryer

for trimming which perfects the insulators into their final form. In drying the product to the bone-dry stage the modern tunnel dryer has given the manufacturer a means of drying under carefully controlled conditions as to temperature and humidity. This is of primary importance in drying the material with the minimum amount of strain and at the same time provides a method which is labor saving. A truck carries the insulators through the dryers and they are then taken directly to the glazing department where the glaze and sand coatings are applied.

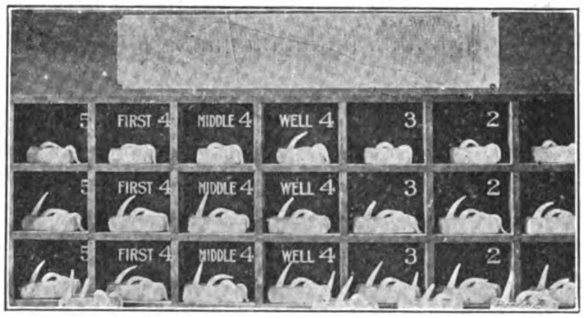

Fig. 12—Typical Photographic Record of Kiln Firing

The color of the glaze has proved of some assistance in indicating the degree of heat treatment received in the kilns. This method, however, has its limitations and is not completely satisfactory.

Recent experimental work in the laboratory has shown that there is a possibility of having the glaze indicate firing treatment by means of its luster. If this glaze can be made satisfactory to the trade, there is no doubt that it will provide a very accurate means of

determining the degree of heat the insulator has received in the kiln.

In firing the material, various steps are taken to insure a uniform product such as the location of numerous cone plaques in all parts of the kilns and the use of the electric pyrometer with recording chart which is operated according to a standard firing curve in order to standardize the entire firing cycle. The cone plaques are marked according to their position in the kiln, so that upon removal if any show that insufficient heat has been received, the insulators which are immediately adjacent to such a cone plaque can be segregated and refired. At the same time all of the cone plaques from one kiln are gathered together and assembled in a rack which is photographed together with the pyrometer chart for the kiln. This gives a complete and permanent record of the firing of each kiln and also determines the efficiency of each kiln and of the kiln firemen. (Fig. 12.)

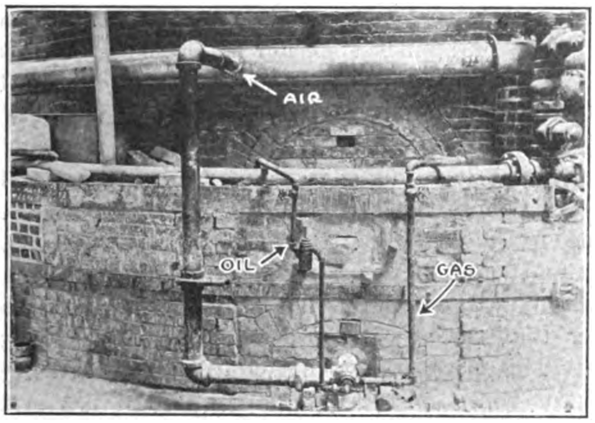

FIG. 13—COMBINATION OIL AND GAS BURNER

Natural gas, coal and more recently oil are used as fuels. Natural gas is undoubtedly the most desirable fuel because of the ease of control and comparatively low temperatures in the fire boxes. The works are located in the natural gas fields where the supply is abundant. However, protective measures by the gas producers have limited the supply during very severe weather. It, therefore, became necessary to resort to other fuels which has brought about the use of oil. This fuel has proved to be much more satisfactory than coal, because its control can be as easily manipulated as that of gas and the only difficulty encountered is the excessive local heat of the oil flame. This has been overcome by the use of superior refractories so that equal results can be obtained with oil, the only difference being in the cost. Coal is, of course, cheaper than oil as far as cost of fuel itself is concerned, but the ease of control and the more uniform and satisfactory results which are obtained from the oil with consequent better quality of finished product has proved conclusively that the final cost of production with oil is cheaper than coal. Combination oil and gas burners are used so that gas can be used whenever available and the change to oil can be made at any time without loss of heat in the kiln. (Fig. 13.)

ROUTINE TESTING

The porcelain parts are carefully inspected as they are drawn from the kilns. Parts having cracks or other defects that can be detected visually are immediately scrapped. Thereafter the parts are subjected to a 60-cycle flash-over test. The characteristics of the transformer are such as to give a 60-cycle voltage with a superimposed high-frequency voltage. Fig. 14 is indicative of the test.

The insulators having cemented hardware are then assembled with neat Portland cement and placed in a closed chamber where they are subjected to an atmosphere of steam during the initial set of the cement. The insulators are then given a routine mechanical test at a load dependent upon the inherent design of the insulator and its application. After the routine mechanical test the assembled insulators are again subjected to a flash-over test, similar in characteristics to that applied to the porcelain parts. It is not necessary, of course, to give the suspension insulators not assembled with hardware a second electrical test.

DESIGN TESTS

It is very difficult to provide tests which will duplicate service conditions since it is impossible to reproduce in short periods of time in the laboratory the temperature cyclic changes which will occur in line service. Although engineers who are familiar with the testing of electrical porcelain do not feel satisfied with laboratory tests, nevertheless all agree that the design which passes severe laboratory tests has apparent merits.

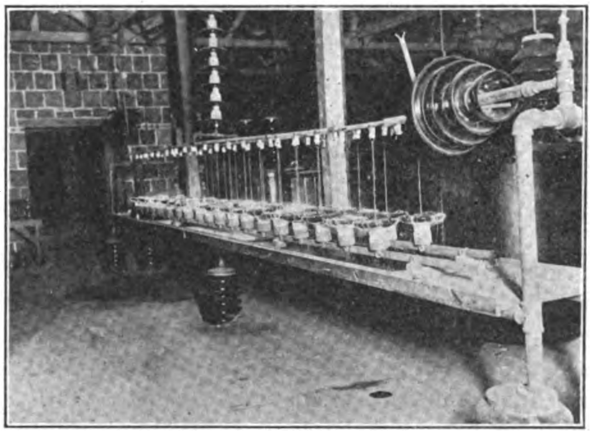
FIG. 14—ROUTINE ELECTRICAL TEST OF PORCELAIN PARTS

Many articles have been published in the engineering periodicals during the last few years discussing types and causes of failures of electrical porcelain. These articles have been presented by men in the field and by representatives of the manufacturers. In general, engineers agree that the failure of suspension insulators having cemented hardware is largely due to

two causes. First: Porosity. Second: Mechanical stresses.

No doubt, porosity was one of the vital factors in causing the failure of the suspension insulators manufactured prior to about 1914. It is not necessary to go into a discussion of the causes of porosity. A brief statement that the porous insulator is an insulator that is underfired is perhaps sufficient. Of course, if we consider the problems of the manufacturer it may be that the material is not properly fired, that the ingredients are not properly proportioned or ground, etc. The subject of porosity affords sufficient information for an article. Now that due consideration is given to all of these factors, the more progressive manufacturers have practically eliminated porous ware.

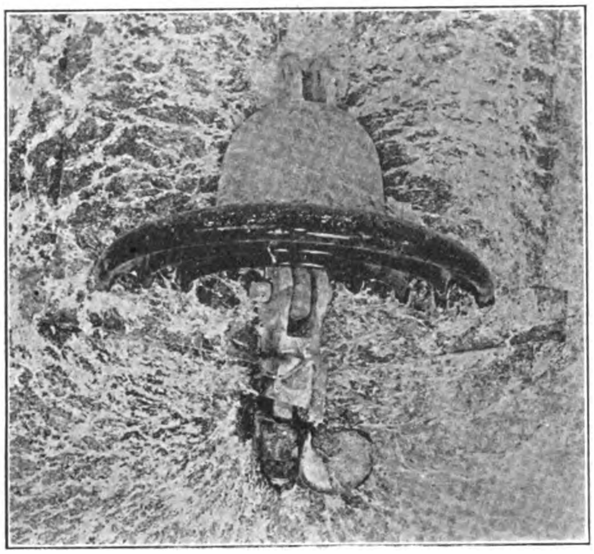

FIG. 15—DIELECTRIC FIELD OF CAP AND PIN SUSPENSION INSULATOR

Second: Mechanical stresses have always been instrumental in the failure of suspension insulators having cemented hardware. Although porosity may have been a vital factor prior to about 1914, mechanical stresses have continued to give trouble and are more difficult to eliminate. The subject of mechanical stress has also been very generally discussed in the engineering periodicals and everyone is familiar with the present assembly methods and the very gratifying results obtained. The elimination of the mechanical stresses caused by temperature changes without doubt, depends upon first, the design; second, the assembly of the hardware and porcelain; third, the setting of the cement under temperature and moisture conditions, etc.

It is impossible to give in any detail an analysis of the design tests which our engineers have made during the past few months. In order to give a general picture of the problems involved, the various lines of research are indicated by the following paragraphs.

ELECTROSTATIC FIELD

The cap and pin suspension insulator or the interlinked type insulator do not represent ideal electrical designs from a consideration of the electrostatic field. However, it is necessary in nearly all commercial designs to sacrifice some efficiency of electrical design to produce a commercial unit which will be economical under the average conditions, *i. e.*, a unit which will perform satisfactorily in dry climates, or in humid climates, indoors, outdoors, etc. The design of insulators based on theoretical principles is discussed in considerable detail in a paper presented before the American Institute in June 1918.[2] It is not necessary to go into a detailed discussion of the electrostatic design of suspension insulators since everyone is somewhat familiar with the theoretical principles.

For general information and interest, Figs. 15 and 16 are included. Fig. 15 pictures the electrostatic field of the cap and pin suspension insulator; Fig. 16 pictures that of the interlinked insulator. To obtain the most efficient electrical characteristics the lines of of force in the area about the insulator should be either parallel or perpendicular to the surface of the insulating material. It is interesting to note the difference in the field about the two suspension insulators. As a matter of fact, the distribution of the stress in the air about the interlinked type insulator is materially better than the distribution about the cap and pin type. This perhaps, explains why the interlinked type insulator has a flash-over comparable to that of the cap and pin type, although there is more corona formation around the interlinking hardware of the interlinked insulator below flash-over than about the cap and pin. It is probable, however, that the corona formation does not build up as rapidly over the surface of the insulator sheds as in the case of the cap and pin because of the more favorable electrostatic field.

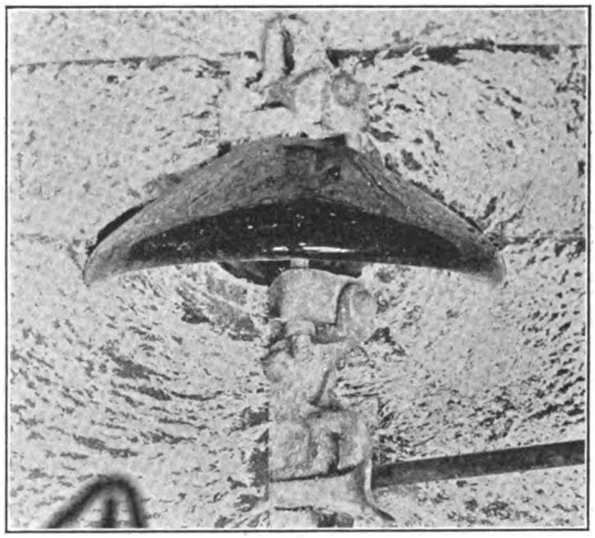

FIG. 16—DIELECTRIC FIELD OF INTERLINKED INSULATOR

Several authors have discussed the advisability of

2. *Application of Theory and Practise to the Design of Transmission Line Insulators*, G. I. Gilchrest, TRANS. A. I. E. E., 1918.

obtaining an insulating material having a low dielectric constant or a high dielectric constant. Obviously it is possible to divert further from the theoretical principles in the design of the insulator if the material has a dielectric constant approaching that of air. Electrical porcelain has a dielectric constant of approximately five compared to the dielectric constant of one of air. It is impossible to vary this constant to any great extent by changing the composition of electrical porcelain.

To the practical engineer it may appear that investigations of the field form of insulators are of no particular consequence. However, the determination of field form of a separate unit or assembled units is particularly useful in determining the concentration of stress. Although experimental methods indicated in the figures do not give the distribution of stress, nevertheless when obtaining the results the investigator can determine the sections of high local stress by the manner in which the particles of material act during the experiment. This method of investigation is applicable to strings of units as well as to separate units.

Mechanical Stress

It is, perhaps, more difficult to provide tests to indicate the comparative resistance of insulators to temperature changes. We have followed a number of lines of investigation and will very briefly discuss each line.

Special Design of Eyebolt

A theoretical analysis of the mechanical stress transmitted to the porcelain by the cemented hardware indicates clearly that the expansion of the eyebolt is probably the most serious factor. To definitely determine this in the laboratory, porcelains assembled with caps alone, with eyebolts alone, and without hardware, were tested by alternate immersions in hot and cold water baths. The porcelain parts assembled with eyebolts alone failed under the same severity of tests as the assembled insulators. The porcelain parts without hardware and with caps alone did not fail under any of the temperature change tests.

Several modifications of the solid eyebolt were then considered and two special types were produced and tested. These were assembled with identical porcelain parts and metal caps and under the same conditions. The two modifications consisted of (A) an eyebolt having two drop forgings assembled with a porcelain sleeve. (B) eyebolt having a one-piece drop forging with a metal sleeve into which the eyebolt could be turned.

These two special designs were compared directly with standard design having the solid eyebolt. The insulators were tested by immersing them alternately in water baths maintained at zero and 100 degrees centigrade. The periods of immersion were varied from one minute at the start to ten minutes at the end. The insulators were not under mechanical load during the tests. Briefly the results of this were as in Table I.

TABLE 1

	Number of Failures under Test								Passing all Tests
	1	2	3	4	5	6	7	8	
Solid Eyebolt	1			4	5		2	2	2
Eyebolt with porcelain sleeve						1	2	6	5
Eyebolt with metal sleeve									14

From an analysis of this table it is very apparent that the insulators having a separable metal sleeve resisted the mechanical stresses from temperature changes more successfully than the insulators having the solid eyebolt or the eyebolt with the porcelain sleeve. Also the insulators having the eyebolt with a porcelain sleeve resisted the mechanical stress better than the insulators with the solid eyebolt.

The inherent design of these insulators is such that the ultimate strength and the combined mechanical and electrical strength are practically identical. Under combined electrical and mechanical test the type with the solid eyebolt gave the highest results averaging between 10,000 and 11,000 pounds. The insulator with the eyebolt having the porcelain sleeve averaged between 9,000 and 10,000 pounds the insulator having the separable metal sleeve averaged between 8000 and 10,000 pounds. The lower strength of the two special types was due largely to the lower strength of the eyebolts. Later, additional samples were made which gave practically the same combined mechanical and electrical test as the solid eyebolt type.

After making these preliminary tests with insulators not subjected to mechanical load, it was thought particularly desirable to have similar tests made with the insulators under tension. The three designs were again tested under a series of temperature changes at 4000 and 5000 pounds load. During the immersions, the insulators were assembled in strings in series with a dynamometer as indicated in Fig. 17.

The load on the insulators shifted somewhat during the transfer from the hot water bath to the cold water. This amount of change varied for the different units and is, perhaps, somewhat indicative of the rigidity of the assembly. It is obvious that the insulator showing the least change of load must have the greatest resilience in its assembly.

	Load Shift under		Per cent Loss	Combined Electrical and Mechanical Strength
	4000 lb.	5000 lb.		
Solid Eyebold (corrugated)	700	625	50	11,350
Solid Eyebolt (sanded)	425	375	40	11,640
Metal Sleeve	750	500	20	11,090
Porcelain Sleeve	825	525	30	10,760

All of the failures occurred during the test under 5000 pounds load. In these tests the insulator having the eyebolt with a metal thimble again proved superior. A portion of the porcelain parts assembled with the solid eyebolt had corrugated gripping surfaces and a portion sanded surfaces. The insulators with the sanded surfaces proved superior in resisting temperature changes and gave less change in load during test, indicating that the sanded surface affords greater resilience than the corrugated surface.

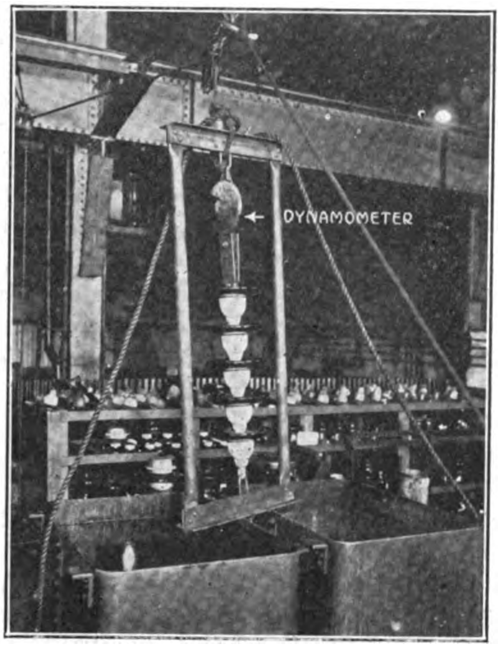

Fig. 17—Testing Insulators by Temperature Changes

Although the insulators with the special design of eyebolt proved superior to the type with the solid eyebolt, it is not possible to determine in the laboratory whether or not service results will be particularly better. We have, however, sufficient of each type now in transmission line service to determine, we believe, in the next two or three years, whether or not there is any advantage in these modifications. However, the improvements in design and assembly have resulted in insulators of solid eyebolt type, that will undergo these laboratory tests without failure.

Special Cement

A number of investigators have contended that Portland cement may be the cause of some of the line failures. They contend that the cement gradually crystallizes and that it may transmit mechanical stresses to the porcelain. Moreover, the coefficient of expansion of cement is greater than that of porcelain and this may increase the hazard. In an attempt to lower the coefficient of expansion of the cement ground porcelain was mixed with the cement. The materials were ground together in ball mills in the proportion of one part porcelain to three parts cement. Standard tensile briquettes made from this mixture gave an average of 327 pounds after 48 hours. Suspension insulators assembled with this material gave the same ultimate mechanical strength as when assembled with neat Portland cement. The results of these initial tests are so encouraging that the investigation will be continued.

Abrasion Tests

Probably porcelain that is most resistant to grinding will better resist weathering conditions, the action of acid, moisture, etc. Occasionally, sections from commercial and special insulators are tested to determine their comparative resistance to abrasion.

As an example of the variation, a test of pieces from three commercial insulators of different manufacture is given. The samples were ground under the same pressure and the same area subjected to grinding. The loss in grams per square inch of surface for each minute of grinding was:

No. 1—0.075
No. 2—0.080
No. 3—0.087

It is very apparent that there is a considerable variation in the mechanical structure. Undoubtedly, the individual insulators of any one manufacturer would vary, but the difference is also due to some extent to the materials used and to the factory processes.

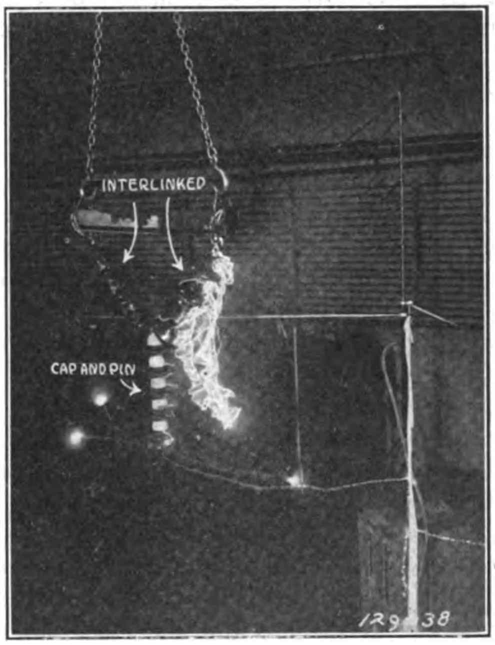

Fig. 18—60-Cycle Wet Flash-Over of Assembled String

Flash-Over Tests

The electrical stress impressed on insulators in line service has been discussed in so many papers that it is entirely unnecessary to go into any detail at this time. The distribution of stress over suspension insulators and the flash-over characteristics of strings of insulators would require a separate paper. Without any special metal fittings to effect a better distribution, the line unit of a string of suspension insulators will assume from

20 to 40 per cent of the total line voltage depending upon the number of insulators in the string, upon the design of the insulator, etc. Many curves of distribution have been published and everyone is familiar with the general shape of these curves which indicate that the line unit or the two units next to the line have much greater than the average stresses impressed upon them.

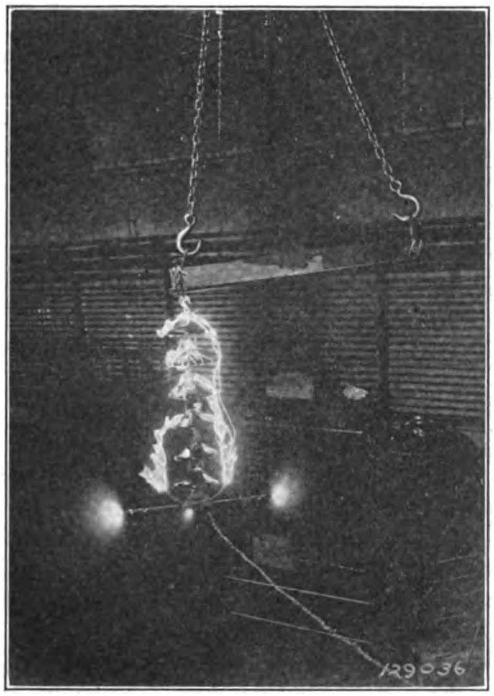

FIG. 19—60-CYCLE FLASH-OVER OF ASSEMBLED STRING

The installation of transmission lines operating at 150 to 220,000 volts, makes it necessary to give careful thought to the concentration of stress upon individual units. The insulators will be subjected to extremely high stresses whenever a flash-over occurs or whenever surges are impressed upon the line from switching, lightning, etc. Fig. 18 is indicative of the stresses from flash-over. This figure shows wet flash-overs on a combination of the interlinked insulators and cap and pin insulators. The interlinked insulators form the *V* part on the string. It is interesting to note the parallel arcs which occur under wet flash-over. Fig. 19 shows a dry flash-over on a string of interlinked insulators. A study of these flash-overs by means of a high-speed camera is giving good results.

CONCLUSIONS

We should at all times consider that porcelain is an extremely fragile material, and that very careful thought must be given to the assembly of porcelain with metal parts, especially if the assembled unit will be subject to severe temperature changes or to mechanical vibrations.

Rapid strides in electrical procelain manufacture have been made during the past few years. Perhaps the greatest advancement is in the methods of production in the factory.

The manufacturers are very open to suggestions from the field and solicit the constructive criticisms which can, perhaps, be given to better advantage by men from the field than by men in the factory. This attitude will continue to react to the mutual advantage of all.

WATER POWER DEVELOPMENT IN QUEBEC

In a review of the industrial and commercial developments in the Province of Quebec, *Commerce Reports* states that the estimated water power available in Canada is some 19,000,000 horse power of which 6,850,000 at 36 per cent is in the Province of Quebec. Of this amount 850,000 have been developed. This has resulted in the creation of such thriving manufacturing towns as Shawinigan Falls, Grand 'Mere, and La Tuque. At Shawinigan Falls, the center of the chemical industry, the electrical generating capacity is 600,000 horse power.

Practically all the electric energy in the Province is now generated by water power and all the large pulp and paper mills, with possibly one exception, are operated by hydroelectric power. Much incentive and assistance is given to water-power undertakings through the activities of the Quebec Streams Commission. The aim of this commission is mainly to improve water-power conditions through water conservation, storage, or otherwise, thus greatly increasing the possible water power available at various sites, thereby rendering them more attractive. The activities of the commission include water conservation storage reservoirs already, constructed and in operation and surveys for future work.

Important additions are reported to be in progress at a number of large hydroelectric plants, such as Cedars on the St. Lawrence, and Shawinigan and Grand 'Mere on the St. Maurice. These extensions aggregate an additional capacity of 130,000 horse power, while a development of 150,000 horsepower is under consideration at Les Gres Falls on the St. Maurice River. The city of Montreal has recently contracted for a large block of power to operate its new electric waterworks pumps, the maximum being 15,000 horse power. The first part of the work in electrifying the harbor railway has been completed; the total trackage is 58 miles, involving an ultimate capacity of some 4000 horse power. A new 800-horse power development to operate rubber works has been completed on the North River at St. Jerome, while new developments or extensions now under construction comprise an addition of 2600 horse power at Deschambault; 2000 horse power at St. Raphael; 4000 horse power at Magog in connection with textile works, and 600 horse power at Lachute.

A Solution of the Porcelain Insulator Problem

By E. E. F. CREIGHTON and F. L. HUNT

General Electric Co., Schenectady, N. Y. Turner Falls Power and Electric Co.

MANY YEARS ago porcelain insulators on transmission lines began to crack in great numbers. In the earlier cases a few disks in many strings had cracked before the transmission engineers had discovered the condition. Indeed, there was at that time no reason to believe that insulators would deteriorate in any way. As a result of these many unobserved failures which simply reduced the factor of safety in each insulator one accidental failure finally introduced surges which punctured many other insulators just on the point of failure. These failures were tens of miles apart. Thereby the whole system was put out of use.

Today these general failures are avoided by a systematic test of each disk at intervals of time depending upon the conditions of installation and the judgment of the transmission engineers.

The cause of most of the failures of these insulators may possibly be reduced to one condition, namely the presence of the Portland cement. To be sure, the Portland cement at times was only indirectly the cause when it simply supplied the moisture which very slowly distilled into porous porcelain. The most usual cause of failure of the disks, however, was due to a characteristic of Portland cement itself. When Portland cement is dried out it shrinks. When it is again wet it expands not only back to its initial size, but a little more. In each cycle of drying and re-wetting the cement increases in volume until it tightly fills the entire space between the metallic hardware and the porcelain. When this condition is reached an unusually warm day will cause an unusual expansion of the metal, and the resulting strain will be transmitted directly through the Portland cement to the porcelain. A crack will result.

Progress in decreasing these failures has been made by the manufacturers of porcelain insulators. For example, instead of resting the cap directly on the porcelain of the usual suspension insulator it is now separated by a slight clearance which prevents the cap from pushing the head off the insulator. This improvement is easily made and has no detrimental factor.

For the expansion of the pin the conditions have been possibly somewhat improved by the use of a layer of soft material next to the porcelain. Unless other conditions are made to conform with this change the insulator is weakened mechanically.

Improvements have been made in the matter of open porosity by greater care in firing. Some manufacturers have also endeavored to overcome this difficulty by glazing all surfaces.

In spite, however, of all of these conditions, the older insulators on transmission lines from all manufacturing companies still fail in sufficient percentages to require the expense of a periodic test and examination. There is an amelioration without a cure. In other words, the life of the insulator has been increased but the tests must still be continued.

The writers attempted to find several solutions of this problem and there is described herewith the satisfactory results of one of these methods. Porcelain disks and hardware were purchased, unassembled, from a reliable manufacturer of insulators. The porcelains were all examined relative to porosity. They were all highly vitrified, in fact there was not the slightest trace of open porosity in a single one of them. A few faults were on the side of overvitrification which manifested itself in a detrimental way by slight checks. Punctures, where they occurred, took place through these checks. Very severe high-frequency voltages were applied by means of the well-known oscillator. The losses due to these extra severe tests were reasonable.

The solution of the main problem—the prevention of failure of the present type of cemented insulators—lies in arresting the expansion of the cement. The easiest method of accomplishing this is by removal of the moisture from the thoroughly set cement and the prevention of its re-entering the cement. This was thoroughly done by impregnation under vacuum on a large number of the insulators and was less thoroughly done on a portion of the insulators with the idea of determining the difference in life, if any, due to the difference in thoroughness of the impregnation.

In the endeavor to reach 100 per cent results it was necessary to study the characteristics of Portland cement when impregnated by different substances. One of the commonest impregnating substances of an insulating nature is paraffin.[1] It was found, however, that a chunk of Portland cement that had been thoroughly impregnated with paraffin by vacuum and heat treatment and then broken would still absorb moisture through the broken surfaces. A better material was therefore looked for. Some of the pitches were found to give perfect results. Portland cement impregnated with pitch could be broken into small pieces and soaked in water for days without the slightest indication of absorption of the water.

As already stated, different methods of impregnation were applied. This work was done in the labora-

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

1. U. S. Pat. 1,360, 896.

tory during 1917 and the spring of 1918. The majority of the insulators were given a thorough vacuum treatment under heat and were impregnated under pressure with the intention and hope of getting 100 per cent perfection and a life of indefinite length—much more than twenty years. In order to get a forecast of the future, laboratory processes of aging were developed. A large wheel, twelve feet in diameter, which is known in the laboratory as the Ferris wheel, was made and operated with the axis in a horizontal plane. Around the rim insulators were secured with bolts and these insulators were passed through a cooling box next to the floor and a heating chamber near the ceiling. The insulators were exposed to the air between these two extremes of heat and an actual blast of moist air was turned on them as they slowly moved around. Here was a device then that gave the extremes of temperature and moisture from 20 deg. cent. below zero to 120 deg. cent. above. The range of temperature and moisture was exaggerated and the rate of change of temperature and moisture was also exaggerated above that found in practise with the idea of hastening any effect that might develop in actual practise. It was estimated that the effect of a single revolution on this wheel would give the insulator more severe strain than would take place in six months in practise—in other words, that two revolutions were equivalent to a year. In this way artificial tests were made extending over more years than any of us will live to enjoy.

In criticism of this method it should be pointed out that it does not give a thorough test of the distillation of moisture into porous porcelain, but it has already been pointed out that these insulators were absolutely without open pores and that consequently that particular feature was not of interest.

Another set of tests was made on these insulators which was more severe in the rate of change of temperature, namely by changing from boiling water to freezing water every half-hour. By these methods we satisfied ourselves that the inpregnation was effective and that the insulators were ready for installation.

The Most Important Conclusions to Date

Eleven hundred of these insulators, carefully marked, were installed on a 66,000-volt transmission line near the seashore in New England in July and August, 1918, and put into operation in November, 1918. *Up to the present time there has not been a single failure among the lot.*

Thirty-six hundred other insulators of the same design, and built in the same factory, were shipped direct from the factory, having been assembled at the insulator factory, and installed on the same line at the same time as the others.

A test made on the whole line about a year after it was put into operation showed 13½ *per cent of failures among the insulators* which came direct from the insulator factory and *no failure at all on those which had received the above described treatment.* The insulators were then about two years old.

Up to the present time there have been additional failures, amounting to 2 or 3 per cent, among the insulators which came direct from the factory, but no failures whatever in the insulators in which the cement was treated.

Following are some comments relating to (1) the mechanical strength, (2) electrical tests treatment, (3) line testing, (4) aging of porcelain, and (5) open porosity of porcelain—which seem pertinent to the subject in hand.

1. *Mechanical Strength.* In discussing the mechanical strength of insulators as affected by impregnation of the cement, it is desirable to avoid the introduction of other factors which are independent of the treatment of the cement. For example, it is well-known that the geometrical dimensions play a leading part in determining the mechanical strength. A large head and a deep pin-hole give more bearing surface for the cement and thereby increase the ultimate "pull" on the hardware. Therefore a type of disk and hardware will have a fairly definite mechanical strength if the cementing is done in the most favorable way.

If the cement is sufficiently set to transmit the force to give the ultimate strength of porcelain in tension (about 2000 pounds per square inch, 140 kg. per square centimeter) and, furthermore, fills the space between hardware and porcelain surfaces sufficiently snugly to transmit the mechanical force uniformly, what more can be asked of the cement? The type of insulator will then give its maximum mechanical "pull."

To arrive at this desired condition the manufacturing details depend on the application of a few scientifically determined factors. To illustrate briefly: The problem of attaining the proper conditions of the cement was approached by experimenting first with the two extremes. At one extreme the cement was set rapidly in live steam at a pressure of 120 pounds per square inch (8.5 kg. per square centimeter). Most of the disks came out of this treatment with the porcelain cracked due to the expansion of the Portland cement. At the other extreme the cement was set for a few days only under conditions of normal room temperature. As a result, either the pin slipped out of the cement in the "pull" test (as was usual) or the cap slipped over the cement. Sufficient "set" and "snugness" of the cement may be obtained by a manipulation of the factors at either extreme—less time and steam temperature starting from the upper extreme or more time and temperature starting from the lower extreme.

It is impracticable to give details here in this brief account. The treatment must be adjusted to the type of cement. For example, some of the grey cements seems to have common characteristics. It is possible

that refinements in the research would show variations in the cement of the same manufacturer at different times of manufacture. We did not go that far. White cement showed the greatest expansion.

The important point in the proposed solution of this problem is that when the cement is given a desirable "set" and "fit" the impregnation excludes moisture which would otherwise change the optimum conditions as the cement grew older. The impregnating material must, of course, be of such a chemical nature as not to attack the cement. If the factors which cause changes in the cement are excluded why will not the cement remain constant forever?

2. *Electrical Tests.* The insulators at the factory and also the specially treated ones in the laboratory were given severe high-frequency tests. Those authorities who have expressed their fear of permanent damage to the porcelain body by the severe electrical tests may feel inclined to explain the loss of over 13 per cent in only two years of life by attributing it to the severity of the tests. This would seem hardly tenable ground. The insulators with impregnated cement were also given the severe electrical tests and none has failed. Is it not more probable that in the assembly of porcelain and hardware in the factory the particular cement and the particular treatment of it expanded the cement to a snug fit and the alternate dry and moist winds of the New England coast caused a further expansion of the tightly fitting cement, followed by a resulting breakage of the porcelain?

3. *Line Testing.* Again it is desirable to emphasize the fact that 100 per cent perfect insulators are a good investment financially, while the extra money expended in *improving* the insulator is of questionable economy. In one case the expensive and dangerous line tests are not necessary, whereas in the other case the line tests are still necessary although they may be made somewhat less frequently. It takes just as long to test 1000 insulators containing one defective as with a number of defectives. The goal is *no testing.*

4. *Aging of Porcelain.* The aging of porcelain is a question frequently brought up. Distinction should be carefully made between the deterioration of insulators and the deterioration of porcelain. There can be no question regarding the former. There is, however, a grave question whether porcelain in itself deteriorates with age. The series of tests of the application of heat, cold, and moisture to normal porcelain, which may be described at a later date, gave not the slightest indication of any change in the porcelain structure. By normal porcelain is meant the combination of clay, feldspar, and flint in the proportion of about 5, 3 and 2 respectively and fired to a vitrification sufficient to do away with open pores. The time and temperature are of the order of 4 to 6 hours at about 1330 deg. cent. The tests used to discover any possible changes in the porcelain were: puncture tests on 60 cycles and 200,000 cycles, hysteresis tests, and impregnation tests of dyes on broken pieces of the porcelain. While it is tenable that improperly made porcelain, using certain grades of quartz instead of flint and introducing other foreign chemicals, such as might come in the ball clay or other ingredients, may deteriorate in time, we have not yet found any such results in our researches. Porcelain protected by glaze is naturally free from moisture. It is therefore, in an insulator, subjected only to the range of atmospheric temperature and the mechanical strains due to the suspended transmission lines. While silica assumes a number of molecular conditions at unusually high temperatures there seems little likelihood that molecular changes at atmospheric temperatures could be a source of deterioration. The chance of deterioration is such a slight factor as compared to more evident conditions that we may properly relegate it to a secondary position for the present in analyzing the faults in porcelain insulators. To be sure, if the porcelain is openly porous and moisture is gradually distilled into the pores and is there frozen, the expansion of the moisture in the cells of the porcelain may increase the porosity. This is not an argument proving the deterioration of porcelain with age, but an argument favoring the proper vitrification of the porcelain, and the glazing of the surfaces exposed to moisture to take care of those inevitable cases of slight undervitrification.

5. *Open Porosity of Porcelain.* In conclusion it should be noted that the use of dry impregnated cement solves also the problem of deterioration of resistance of porcelain due to the absorption of moisture.

As an incidental auxiliary matter, the manufacturer, by request, supplied a few special, underfired insulators for comparison and a method of determining the underfired condition, without destroying the porcelain, was tried. This laboratory test was of the nature of hysteresis loss in the material. A description of it is out of the scope of the present paper. None of these was installed.

Final Comments. Three to four years is not sufficient time to furnish absolute proof of the success of this impregnation method. More reliance is placed on the artificial aging test of the laboratory. There are points for discussion and debate and more work yet to be done. We present the matter as a progressive step.

Transformers for Interconnecting High-Voltage Transmission Systems

For Feeding Synchronous Condensers from a Tertiary Winding

BY J. F. PETERS and M. E. SKINNER

Both of the Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Owing to the advantages to be realized from the use of the star-star connection in interconnecting high-voltage transmission systems and from the fact that this connection requires the use of an auxiliary winding connected in delta to stabilize the neutral point or to decrease the inductance in the ground connection, a great majority of the transformers designed for interconnecting transmission lines are three-winding transformers. Another type of transformer which would be included in this general class would be that having an auxiliary winding for feeding a synchronous condenser used in controlling the voltage at the receiver end of the line.

Many of the alternatives such as the choice between self-cooling or water-cooling, or between single-phase units and three-phase units, differ in no way from the same questions on transformers for ordinary service. However, there are a number of important features peculiar to three-winding transformers for these classes of service that complicate the design and operation to an extent that justifies special consideration of these problems.

This paper will call attention to these special problems and indicate the way in which the design and performance of transformers for these classes of service are influenced by them.

Phase Displacement Between Interconnected Systems

If TWO transmission systems are tied in at one point only, the phase displacement between the two systems is fixed by the transformer connection which is used at that point. Future interconnections between the two systems must be consistent with those which have preceded them. A 30-deg. phase displacement would require the use of a delta-star connection. A 0-deg. or 180-deg. phase displacement would require the use of either the delta-delta or the star-star connection. The most common condition is probably 0-deg. phase displacement in which case there is a choice between the use of the delta-delta or the star-star connection. The logical choice between these two alternatives is the star-star connection for the following reasons:

First. It reduces the average insulation stress between the windings and the core of the transformer.

Second. It offers an opportunity to ground either or both the system neutrals at the transformer.

Third. It results in a cheaper and smaller transformer.

Fourth. It offers an opportunity for further reduction in first cost when the neutrals are grounded by the use of graded insulation.

Fifth. It offers an opportunity for further reduction in first cost by the elimination of one high-voltage bushing.

Economy of Star-Connected Transformers

The average voltage stress between windings and core is 43.3 per cent of the line voltage in a delta-connected winding, but only 28.9 per cent in a star-connected winding, the latter figure being just two-thirds of the former.

A star-connected transformer is cheaper to build than a delta-connected one because of the better space factor resulting from the fewer number of turns of correspondingly larger cross-section. The difference between the costs of the two is a function of the voltage and of the capacity of the transformer, and becomes more marked as the voltage increases and the capacity decreases. The dry weight of a transformer, *i. e.*, the weight of the transformer with its case but exclusive of the oil, is sometimes used as a criterion of the cost of transformers. Fig. 1 shows the relation between the dry weights of star- and delta-connected

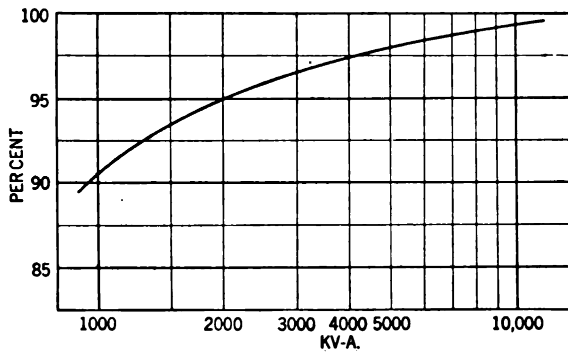

Fig. 1—Dry Weight of One-Phase, 60-Cycle, 66-Kv. Star-Connected Transformers in Per Cent of Equivalent Delta-Connected Transformers

single-phase, 60-cycle, 66,000-volt transformers, and the kv-a. of the transformer. The dry weight of the star-connected transformer is expressed as a percentage of the dry weight of the delta-connected transformer of the same rating. The saving of the star connection over the delta connection is evident from this curve. For higher voltage classes the differences would be still more marked, while for very low voltages they become negligible. In fact, for extremely low voltages the heavier current may be a handicap and throw the difference in favor of the delta connection. The economies effected through the use of the

star connection for high voltages often result in a reduction in the dimensions as well as the cost.

When the neutral of the system is directly grounded at both ends of the line it is often the practise on star-connected transformers to taper the insulation between the windings and the core more or less in proportion to the stress between them and to test them with an induced voltage rather than a disruptive test. The Standardization Rules of the A. I. E. E., Article 6361-e, specify the test for apparatus connected to permanently grounded single-phase circuits of more than 300 volts as 2.73 times the voltage to ground + 1000 volts, but the same rule specifically states that this test shall not apply on three-phase apparatus with grounded star neutral. However, where transformers have been supplied in the past with graded insulation, the practise has been to apply the same rule to three-phase circuits until this practise is now pretty well established. Grading the insulation between winding and core proportionately with the stresses, results in a considerable saving and makes it possible to eliminate one of the high-voltage bushings. The cost of high-voltage bushings is quite an item and the increased clearances possible with only one high-voltage bushing through the cover make for greater safety.

Star-Star Connection is Adapted to the Use of Auto-Transformation

An auto-transformer offers a decided saving in first cost over an equivalent transformer with separate windings but it can only be applied under certain conditions. These conditions are fulfilled with the star-star connection when the neutral point is directly and permanently grounded. If the neutral of the three-phase star-star connected auto-transformer is not directly and permanently grounded, serious stresses will be put upon the system having the lower line voltage in the event of one of the higher voltage lines grounding accidentally. Assume a three-phase star-star connected auto-transformer stepping down from 150,000 volts and 66,000 volts with the neutral free. In the event of a ground on one of the 150,000-volt lines the potential of the 66,000-volt lines above ground would be increased from 38,100 volts to 48,500 volts on the line in the same phase on which the ground occurs and to 110,800 volts on the other two lines. (Fig. 2.)

The amount of saving effected by the use of auto-transformers as compared with transformers with separate windings depends upon the ratio of transformation. The equivalent size of the auto-transformer to transform a certain kv-a. expressed as a fraction of the kv-a. is $\frac{V_1 - V_2}{V_1}$ where V_1 and V_2 are the higher and lower voltages respectively. It is evident from this expression that the greatest reduction in size and cost occurs when V_1 and V_2 are of nearly the same magnitude. If this were the only consideration, the most likely field of application for an auto-transformer would be where the ratio of transformation is nearly unity. However, the impedance of an auto-transformer is lower than that of an equivalent transformer with separate windings, in the same ratio as the equivalent size is reduced, namely $\frac{V_1 - V_2}{V_1}$ so that as V_2 approaches V_1 the impedance approaches O. The low impedance of the auto-transformers in the range of voltage ratios where they present the greatest economy works against them as it allows very heavy currents to flow through them at times of short circuits. When the transformation ratio falls much below 1 to 1.1 it becomes almost impossible to design an auto-transformer which will be self-protecting, *i. e.*, will withstand the forces incident to a dead short circuit with sustained voltage without mechanical injury. The result of this situation has been to limit the application of auto-transformers to that range of voltage ratios where the stresses due to short circuits are within reasonable limits. A review of the past applications of auto-transformers to power transmission systems indicates that the majority of such applications has been where the ratio of transformation was in the vicinity of two to one.

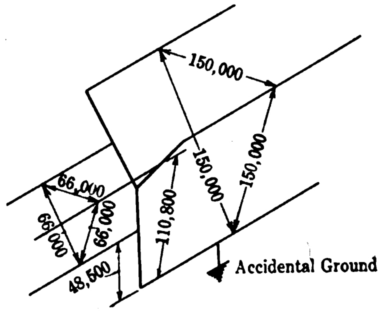

Fig. 2—Voltages to Ground with Star-Star Auto-Transformers and Neutral Free

The economy of the star-star connection, the availability of ground connections, and its adaptability to the use of graded insulation and auto-transformations, gives it a great advantage over the delta-delta connection for use in interconnecting power systems and it has been used almost exclusively in the past where 0-deg. phase displacement is desired.

Star-Star Connection Requires the Use of Auxiliary Winding Connected in Delta

When the star-star connection is employed it is necessary to have an auxiliary or tertiary winding connected in delta to obtain satisfactory operation.[1] In all single-phase transformers and in three-phase transformers of the shell type of construction, a tertiary is necessary in order to supply the triple harmonic component of the exciting current which is suppressed

1. See paper on this subject by Mr. J. F. Peters, Proc. A. I. E. E., August, 1915.

by the star-star connection. If the triple harmonic exciting current is not supplied there will be a triple harmonic in the phase voltage which will produce an unstable neutral. This cannot be permitted on account of the insulation stresses imposed on the system. In the three-phase core type of construction the return circuit for the flux in any leg is through the other two legs. The deficiency in third harmonic excitation in any phase at any given instant is supplied from the other two phases which have an excess of third harmonic excitation at that instant. There are other considerations which will be discussed later, under the effect of the tertiary upon the currents which flow when a high-voltage line accidentally grounds, which make advisable the addition of a tertiary winding in the three-phase core-type transformer even though it is not required to stabilize the neutral.

Use of a Tertiary Winding to Furnish Power for a Synchronous Condenser

A tertiary winding is often used to furnish power to a synchronous condenser used for regulating the voltage at the receiver end of a transmission line. It is often possible to effect a considerable saving by having the transformer, which would be required for the synchronous condenser, combined with the main step-down transformer.

When a condenser is supplying leading kv-a. and the main load is at a lagging power factor the two loads combine to reduce the current flowing in the primary so that the addition of the condenser winding will not increase the size of the primary winding as long as the condenser does not exceed twice the reactive component of the main load. If the condenser load were maintained at all times, it would even be possible to reduce the size of the primary. This is seldom the condition, however, and it is therefore the practise to design the primary so that it will carry full load with the condenser shut down.

The third winding in a transformer, whether it be for stabilizing the neutral point or for reducing the inductance in the connection between neutral and ground in a star-star connected bank or for supplying power to two loads of different power factors, introduces many features which must be recognized in the design and considered in predicting the operating characteristics of such transformers.

Limitations Imposed on Grouping of the Windings

When transformers tie together three systems where the flow of power may be from any one to the other two or vice versa, one of the first requirements is that the reactance between any two windings be of about the same magnitude. If this is not the case, there will be large differences between the regulation with varying conditions of power flow between the interconnected systems. Moreover, with power supply on all three systems, if the reactance is low between any two of them, the currents flowing under short-circuit conditions will become dangerously large and there will be danger of mechanical injury to the transformer. Thus the problem is one of getting high enough reactance between any two windings without making that between any other two excessive.

In the single-phase concentric-coil core type of construction there are two ways in which the three windings may be arranged with respect to one another.

The first arrangement, Fig. 3a, will result in normal reactance between primary and secondary and between secondary and tertiary, but in very high reactance between the primary and the tertiary due to the greater separation and the resultant heavy leakage across the space occupied by the secondary winding. In the second arrangement, Fig. 3b, by making the disposition of the windings on the two legs different it is possible to equalize the reactances between pairs of the windings. This is a rather dangerous compromise however, because the leakage flux between any pair

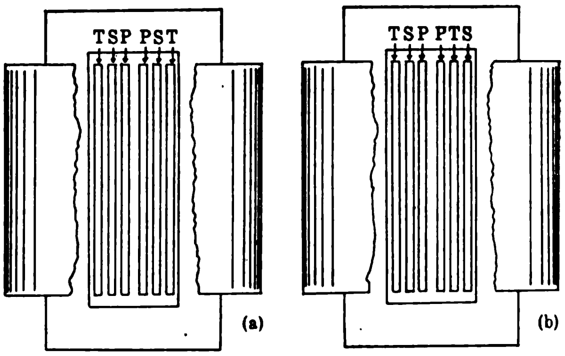

Fig. 3—Partial Section Through Core-Type Transformer Showing Disposition of Windings

of windings in one direction on one leg is greater than that returning on the other leg. The excess will have to return through the space surrounding the transformer and would result in an intolerable condition due to the heating caused by the stray flux. If the loads on both secondaries happened to be in phase the condition would be improved as then the sum of the leakage would be the same on both legs. This is a condition which would be difficult if not impossible of accomplishment under operating conditions. With loads of different power factors the leakage flux between one secondary and the primary would be out of phase with that between the other secondary or tertiary and the primary resulting in the condition just described. In a three-phase concentric-coil core-type transformer there is no alternative but to submit to a high reactance between one pair of windings inasmuch as all the winding for one phase is on one leg.

In a shell-type transformer it is possible on account of the more extensive interlacing of the windings to equalize the reactance between all pairs of windings without causing heavy stray fields through the unbalancing of the leakage flux.

Refer to Fig. 4 and note that each half of the trans-

former is balanced in itself, *i e.*, the total leakage between P_1 and S is the same on the left side of P_1 as on the right side. The total leakage between P_2 and S is also the same on either side but its magnitude is different from that about P_1. The location of T with respect to P in one-half of the opening is the same as that of S in the other half so that the reactance

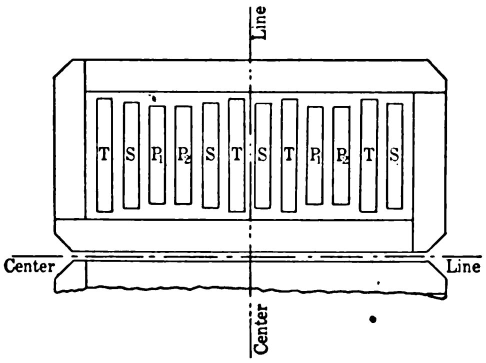

FIG. 4—PARTIAL SECTION THROUGH SHELL-TYPE TRANSFORMER SHOWING DISPOSITION OF WINDINGS

between any pair of windings will be substantially the same without creating an unbalance which will result in heavy leakage fields.

From the foregoing discussion it is quite evident that to design a three-winding transformer to meet certain specified values of reactance between each pair of windings would impose conditions which are extremely difficult and sometimes practically impossible to fulfill. This might be the condition presented to the designer if called upon to design a three-winding transformer to operate in parallel with another unit of different rating.

REGULATION OF THREE-WINDING TRANSFORMERS

A three-winding transformer will usually have different voltage drops from primary to secondary and

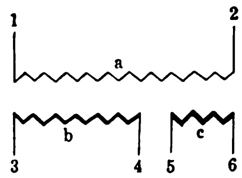

FIG. 5

from primary to tertiary. Moreover, the voltage drop between primary and secondary is usually affected by the load on the tertiary so that if the tertiary is loaded there may be a drop from primary to secondary even though the latter winding is idle.

Let the sub-numbers and sub-letters refer to the windings as indicated in the sketch, Fig. 5.

R = resistance in ohms at reference voltage,
L = self-inductance in henrys,
M = mutual inductance in henrys,
E = reference voltage expressed as a complex quantity,
I = current in winding at reference voltage expressed as a complex quantity,
X = reactance between windings

$$= w\,(L_p - 2\,M_{ps} + L_s)$$
$$= 2w\,(L - M) \text{ where } L_p = L_s.$$

The voltage drop in each winding will be:

$$E_{12} = -\,R_a\,I_{12} - j\,w\,(L_a\,I_{12} + M_{ab}\,I_{34} + M_{ac}\,I_{56}) \quad (1)$$
$$E_{34} = -\,R_b\,I_{34} - j\,w\,(L_b\,I_{34} + M_{ab}\,I_{12} + M_{bc}\,I_{56}) \quad (2)$$
$$E_{56} = -\,R_c\,I_{56} - j\,w\,(L_c\,I_{56} + M_{ac}\,I_{12} + M_{bc}\,I_{34}) \quad (3)$$
$$I_{12} = -\,(I_{34} + I_{56}) \quad (4)$$
$$E_{12} = +\,R_a\,(I_{34} + I_{56}) + j\,w\,[L_a\,(I_{34} + I_{56}) - M_{ab}\,I_{34} - M_{ac}\,I_{56}] \quad (5)$$
$$E_{34} = -\,R_b\,I_{34} - j\,w\,[\,L_b\,I_{34} - M_{ab}\,(I_{34} + I_{56}) + M_{bc}\,I_{56}] \quad (6)$$
$$E_{56} = -\,R_c\,I_{56} - j\,w\,[\,L_c\,I_{56} - M_{ac}\,(I_{34} + I_{56}) + M_{bc}\,I_{34}] \quad (7)$$

The voltage drop from winding a through winding b:

$$-\,(E_{12} - E_{34}) = (R_a + R_b)\,I_{34} + j\,w\,(L_a - 2\,M_{ab} + L_b)\,I_{34} + R_a\,I_{56} + j\,w\,(L_a - M_{ac} - M_{ab} + M_{bc})\,I_{56} \quad (8)$$

Adding $1/2\,j\,w\,(L_b - L_b + L_c - L_c)\,I_{56}$ and recombining,

$$= (R_a + R_b)\,I_{34} + j\,w\,(L_a - 2\,M_{ab} + L_b)\,I_{34} + R_a\,I_{56} + 1/2\,j\,w\,[\,(L_a - 2\,M_{ab} + L_b) + (L_a - 2\,M_{ac} + L_c) - (L_b - 2\,M_{bc} + L_c)\,]\,I_{56} \quad (9)$$

but, $w\,(L_p - 2\,M_{ps} - L_s)$ is the reactance between primary and secondary, then,

$$-\,(E_{12} - E_{34}) = [\,(R_a + R_b) + j\,X_{ab}\,]\,I_{34} + [R_a + 1/2\,j\,(X_{ab} + X_{ac} - X_{bc})\,]\,I_{56} \quad (10)$$

in the same way

$$-\,(E_{12} - E_{56}) = [\,(R_a + R_c) + j\,X_{ac}]\,I_{56} + [R_a + 1/2\,j\,(X_{ab} + X_{ac} - X_{bc})\,]\,I_{34} \quad (11)$$

These voltage drops will appear as complex quantities and may be reduced to percentage by dividing by the reference voltage E. They will then be in the form

$$\pm\,a\,\% \pm j\,b\,\%.$$

Then

$$\%\text{ Regulation} = \pm\,a\,\% + \frac{(\pm\,b\,\%)^2}{200} \quad (12)$$

The sign of the regulation may be positive or negative, a positive sign indicating a drop and a negative sign a rise in voltage as the load is increased.

It will be noticed that in each voltage drop there is a term which depends upon the current which flows in the winding which is not being considered, for instance, in the voltage drop from winding a to winding b there is a component produced by the flow of the current I_{56} in winding c. This indicates that there will be a certain amount of regulation on a winding even at no-load, providing load is being taken from one of the other windings. The condition under which this influence will be a minimum is that $X_{ab} + X_{ac} = X_{bc}$.

The following tables will indicate in a general way how changes in load affect the regulation of a typical

three-winding transformer. The transformer chosen is typical of the type under consideration. It is a 35,000-kv-a., single-phase, 60-cycle, star-star connected transformer designed to step down 30,300 kv-a. at 100 per cent power factor, from 220 kv. to 66 kv. and to supply a synchronous condenser of 17,500-kv-a. capacity at 13 kv., the tertiary winding being connected in delta.

TABLE I

Regulation in per cent with varying condenser load. Load on 66-kv. winding constant at 30,300 kv-a. 100 per cent power factor.

Kv-a. at 0% power factor on condenser	Regulation on 66-kv. line	Regulation on 13-kv. line
100 % leading	− 3.12	− 10.75
75 " "	− 2.12	− 7.95
50 " "	− 1.10	− 5.12
25 " "	− 0.095	− 2.31
0 "	+ 0.91	+ 0.48
25 "lagging	+ 1.92	+ 3.29

TABLE II

Regulation in per cent with varying load. Condenser supplying 17,500 kv-a. at 0 per cent power factor leading.

Kv-a. at 100% power factor on 66-kv. line	Regulation on 66-kv. line	Regulation on 13-kv. line
100%	− 3.12	− 10.75
75	− 3.43	− 10.91
50	− 3.69	− 11.06
25	− 3.89	− 11.18
0	− 4.04	− 11.24

TABLE III

Regulation in per cent with varying power factor on 66-kv. winding. Condenser supplying 17,500 kv-a. at 0 per cent power factor leading

30,300 kv-a. on 66-kv. line at power factor	Reg. on 66-kv. line	Reg. on 13-kv. line
100%	− 3.12	− 10.75
95	− 0.26	− 8.59
90	+ 0.83	− 7.75
85	+ 1.60	− 7.15
80	+ 2.25	− 6.67

Application of Formulas to Auto-Transformers

It has been pointed out that the star-star connected auto-transformer with a tertiary winding is a special case of three-winding transformers.

Following the same system of notation and referring to Fig. 6, note that there are three conditions of loading.

(A) Winding 13 delivering power to, or receiving power from, windings 23 and 45.

(B) Winding 23 delivering power to, or receiving power from, windings 13 and 45.

(C) Winding 45 delivering power to, or receiving power from, windings 13 and 23.

Case A. Let I with proper subscript = current due to load on auto-transformers.

Let I' with proper subscript = current due to load on two-winding transformer.

$$\begin{aligned} E_{13} = &- R_a I_{12} - R_b I_{23} - (R_a + R_b) I_{13}' \\ &- j w (L_a I_{12} + L_b I_{23} + M_{ab} I_{12} + M_{ab} I_{23} \\ &+ L_{ab} I_{13}' + M_{ab\text{-}c} I'_{45}) \end{aligned} \tag{13}$$

$$\begin{aligned} E_{23} = &- R_b (I_{23} + I_{13}') - j w [L_b (I_{23} + I_{13}') \\ &+ M_{ab} (I_{12} + I_{13}') + M_{bc} I_{45}'] \end{aligned} \tag{14}$$

$$\begin{aligned} E_{45} = &- R_c I_{45}' - j w (L_c I_{45}' + M_{ac} I_{12} + M_{bc} I_{23} \\ &+ M_{ab\text{-}c} I_{13}') \end{aligned} \tag{15}$$

In order to handle the ratio between windings $a\,b$ and b it is necessary to introduce a factor r.

Let $$\frac{E_{13}}{E_{23}} = r = \frac{E_{12} + E_{23}}{E_{23}} = \frac{E_{12}}{E_{23}} + 1,$$

then $$\frac{E_{12}}{E_{23}} = (r - 1)$$

and $$\frac{I_{12}}{I_{23}} = \frac{1}{r - 1} \text{ or}$$

$$I_{23} = - (r - 1) I_{12}; \text{ also, } I_{45}' = - I_{13}'$$

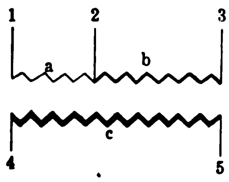

Fig. 6

Then,

$$\begin{aligned} E_{13} = &- [R_a - (r - 1) R_b] I_{12} - R_{ab} I_{13}' - j w [L_a I_{12} \\ &- (r - 1) L_b I_{12} + (2 - r) M_{ab} I_{12} + L_{ab} I_{13}' \\ &- M_{ab\text{-}c} I_{13}'] \end{aligned} \tag{16}$$

$$\begin{aligned} E_{23} = &R_b [(r - 1) I_{12} - I_{13}'] + j w [L_b (r - 1) I_{12} \\ &- L_b I_{13}' - M_{ab} (I_{12} + I_{13}') + M_{bc} I_{13}'] \end{aligned} \tag{17}$$

$$\begin{aligned} E_{45} = &R_c I_{13}' + j w [L_c I_{13}' - M_{ac} I_{12} \\ &+ (r - 1) M_{bc} I_{12} - M_{ab\text{-}c} I_{13}') \end{aligned} \tag{18}$$

The voltage drop from winding a through winding b:

$$\begin{aligned} - (E_{13} - r E_{23}) = &[R_a + (r - 1)^2 R_b] I_{12} \\ &+ j w [L_a - 2 (r - 1) M_{ab} + (r - 1)^2 L_b] I_{12} \\ &+ (R_{ab} + r R_b) I_{13}' + j w (L_{ab} - M_{ab\text{-}c} - r L_b \\ &- r M_{ab} + r M_{bc}) I_{13}' \end{aligned} \tag{19}$$

Adding $1/2 j w (L_c - L_a + r^2 L_b - r^2 L_b) I_{13}'$ and recombining and making use of the relation

$$1/2 L_{ab} = 1/2 (L_a + 2 M_{ab} + L_b)$$

$$\begin{aligned} = &[R_a + (r - 1)^2 R_b] I_{12} + j w [L_a - 2 (r - 1 M_{ab} \\ &+ (r - 1)^2 L_b] I_{12} + (R_{ab} + r R_b) I_{13}' \\ &+ j w 1/2 (L_{ab} - 2 M_{ab\text{-}c} + L_c) I_{13}' + j w 1/2 [L_a \\ &- 2 (r - 1) M_{ab} + (r - 1)^2 L_b] I_{13}' - j w 1/2 (L_c \\ &- 2 r M_{bc} + r^2 L_b) I_{13}' \end{aligned} \tag{20}$$

$$\begin{aligned} = &[R_a + (r - 1)^2 R_b] I_{12} + j X_{ab} I_{12} \\ &+ (R_{ab} + r R_b) I_{13}' + j 1/2 (X_{ab\text{-}c} + X_{ab} \\ &- X_{bc}) I_{13}' \end{aligned} \tag{21}$$

Similarly, the voltage drop from winding a through winding c

$$-(E_{13} - E_{45}) = (R_{ab} + R_c)\, I_{13}' + j\, X_{ab\cdot c}\, I_{13}' + [R_a - (r-1)\, R_b]\, I_{12} + j\, 1/2\, (X_{ab\cdot c} + X_{ab} - X_{bc})\, I_{12} \qquad (22)$$

The regulation may be obtained from these voltage drops in the same way as from equations (11) and (12).

CASE B. Developing this case in exactly the same way results in expressions as follows. The voltage drop from winding b through winding $a\,b$:

$$(r\, E_{23} - E_{13}) = [R_a + (r-1)^2\, R_b]\, I_{12} + j\, X_{ab}\, I_{12} + r\,(r-1)\, R_b\, I_{45}' + j\, 1/2\, (X_{ab} + X_{bc} - X_{ab\cdot c})\, I_{45}' \qquad (23)$$

The voltage drop from winding b through winding c:

$$(r\, E_{23} - E_{45}) = (R_c + r^2\, R_b)\, I_{45}' + j\, X_{bc}\, I_{45}' + r\,(r-1)\, R_b\, I_{12} + j\, 1/2\, (X_{ab} + X_{bc} - X_{ab\cdot c})\, I_{12} \qquad (24)$$

CASE C. In the same manner under this condition the drop from winding c through winding $a\,b$:

$$-(E_{45} - E_{13}) = (R_c + R_{ab})\, I_{45} + j\, X_{ab\cdot c}\, I_{45} + (R_c + r\, R_b)\, I_{45}' + j\, 1/2\, (X_{ab\cdot c} + X_{bc} - X_{ab})\, I_{45}' \qquad (25)$$

and the drop from winding c through winding b:

$$-(E_{45} - r\, E_{23}) = (R_c + r^2\, R_b)\, I_{45}' + j\, X_{bc}\, I_{45}' + (R_c + r\, R_b)\, I_{45} + j\, 1/2\, (X_{ab\cdot c} + X_{bc} - X_{ab})\, I_{45} \qquad (26)$$

Referring back to Fig. 5, assume a short circuit occurs on winding a. Let $R_b' + j\, X_b'$ and $R_c' + j\, X_c'$ represent the impedance of the lines and generators connected to windings b and c, respectively. Including these impedances in the voltage drops as given by equations (10) and (11) we have:

$$-(E_{12} - E_{34}) = [\,(R_a + R_b + R_b') + j\,(X_{ab} + X_b')\,]\, I_{34} + [R_a + 1/2\, j\,(X_{ab} + X_{ac} - X_{bc})\,]\, I_{56} \qquad (27)$$

$$-(E_{12} - E_{56}) = [\,(R_a + R_c + R_c') + j\,(X_{ac} + X_c')\,]\, I_{56} + [R_a + 1/2\, j\,(X_{ab} + X_{ac} - X_{bc})\,]\, I_{34} \qquad (28)$$

Putting

$$Z_2 = R_a + R_b + R_b' + j\,(X_{ab} + X_b') \qquad (29)$$

$$Z_3 = R_a + R_c + R_c' + j\,(X_{ac} + X_c') \qquad (30)$$

$$Z_0 = R_a + 1/2\, j\,(X_{ab} + X_{ac} - X_{bc}) \qquad (31)$$

Equations (27) and (28) may be rewritten:

$$-(E_{12} - E_{34}) = Z_2\, I_{34} + Z_0\, I_{56} \qquad (32)$$

$$-(E_{12} - E_{56}) = Z_3\, I_{56} + Z_0\, I_{34} \qquad (33)$$

Since the drop is the same in both circuits,

$$E = Z_2\, I_{34} + Z_0\, I_{56} = Z_3\, I_{56} + Z_0\, I_{34} \qquad (34)$$

and,

$$I_{34} = \frac{Z_3 - Z_0}{Z_2\, Z_3 - Z_0^2}\, E \qquad (35)$$

$$I_{56} = \frac{Z_2 - Z_0}{Z_2\, Z_3 - Z_0^2}\, E \qquad (36)$$

and adding,

$$I_{12} = \frac{Z_2 + Z_3 - 2 Z_0}{Z_2\, Z_3 - Z_0^2}\, E \qquad (37)$$

The most satisfactory method of calculating short-circuit currents in a complicated network is by the

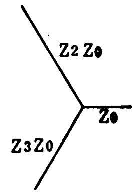

FIG. 7—GRAPHICAL REPRESENTATION OF IMPEDANCES IN A THREE-WINDING TRANSFORMER

use of a calculating board, *i. e.*, by setting up a network of resistances whose values are proportional to the impedances of the various parts of the system, impressing a known voltage, and measuring the currents which flow in the various branches of the network. From these measurements the magnitudes of the actual short-circuit currents are calculated. It is interesting to note from equations (27) and (28) how a three-winding transformer would be set up on such a calculating board. One component of impedance is common to both $-(E_{12} - E_{34})$ and $-(E_{12} - E_{56})$ so that the three-winding transformer may be represented by a three-legged star with legs respectively Z_0, $Z_2 - Z_0$ and $Z_3 - Z_0$. (Fig. 7).

EFFECT OF A TERTIARY WINDING IN LIMITING CURRENT WHICH FLOWS WHEN ONE LINE ACCIDENTALLY GROUNDS

In a star-star connected transformer with a tertiary winding and with the neutral grounded on either or both of the high and low-voltage sides but with the

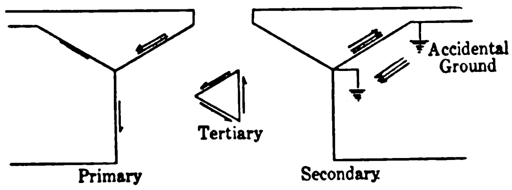

FIG. 8—FLOW OF CURRENT WHEN SECONDARY LINE GROUNDS—STAR-STAR CONNECTION WITH TERTIARY

neutral of the supply not grounded, the magnitude of the current which flows in case of an accidental ground on one of the lines is influenced very largely by the reactance between the main windings and the tertiary. In a transformer with a 1 to 1 turn ratio between all windings the current in the tertiary will always be one-third of the current flowing to ground on the secondary side because this is the only division of current which makes the ampere turns of primary

and secondary equal in each phase. Refer to Fig. 8 which shows quantitatively how the currents would divide under the conditions shown.[2] The ampere turns of phase A on the grounded side are balanced by those in phase A on the primary side and by those in phase $A\,C$ in the tertiary. The conditions which determine the division of current are that the current in each leg of the tertiary be the same since it flows in series through each of them, and that the sum of the currents in phases B and C on the primary side be equal to the current in phase A since the current is a single-phase current. The only way current can divide between phases B and C and fulfill these conditions is to divide equally. Since the currents in phases B and C of the grounded side carry no current, that which flows in the same phases of the primary side must be all balanced by the current in the same phase of the tertiary.

The total magnitude of the ground current usually depends partly upon the impedance of the generators supplying the line to the unbalanced currents which flow through them under such conditions. For this reason it is difficult to calculate accurately as these special impedance measurements are seldom at hand. It is quite evident however that with large capacity back of the transformer, the impedance of the generator and supply lines is relatively small, and the magnitude of the current which flows depends largely upon the impedance between various pairs of windings in the transformer, and may be closely approximated by neglecting the generator and supply line impedance and assuming full voltage maintained. Under this assumption the currents flowing under various combinations of grounding will be as given in Table IV.

I_n = normal current in winding at full load.

Z_o = impedance voltage between primary and secondary in per cent at full load.

Z_t = impedance voltage between primary or secondary and tertiary in per cent at a load in the tertiary corresponding to full load, depending upon the winding under consideration.

2. See Article in the *Elec. Journal*, Nov. 1919, Tertiary Winding in Transformers, Their Effect on Short-Circuit Currents, by J. F. Peters.

This means that in any of these connections the ground connection has more or less inductance in it. The amount of inductance can be minimized by keeping these same impedances to low values. This fact shows why it is necessary to supply a tertiary winding for a three-phase core-type transformer, if there is no tertiary. The ampere turns in the winding which is grounded are balanced by the ampere turns on the other two legs, and the leakage flux would be very great. This is equivalent to a tertiary with very high reactance and means that the ground current would be limited to a very low value. However, it is limited by what is equivalent to inserting a large inductance in the neutral connection. When a three-phase core-type transformer without a tertiary is under consideration Z_t becomes the impedance voltage between the winding on one leg and the windings on the other two connected in parallel in per cent at full load.

TABLE IV

Connection of Transformer bank					Short-circuit Current	
Primary	Secondary	Supply	Side of which fault occurs	Tertiary	In tertiary	In main winding
Star Grounded	Star Grounded	Grounded	Secondary	No	0	$\frac{100\ I_n}{Z_o}$
Star Grounded	Star Grounded	Isolated	Primary	Yes	$\frac{100\ I_n}{Z_t}$	$\frac{100\ I_n}{Z_t}$
Star Grounded	Star Grounded	Isolated	Secondary	Yes	$\frac{100\ I_n}{2Z_o + Z_t}$	$\frac{300\ I_n}{2Z_o + Z_t}$
Star	Star Grounded	Grounded or Isolated	Primary	Yes	0	0
Star	Star Grounded	Grounded or Isolated	Secondary	Yes	$\frac{100\ I_n}{2Z_o + Z_t}$	$\frac{300\ I_n}{2Z\ + Z_t}$

For this reason all transformers for star-star connection should be equipped with tertiary windings and the impedance between main windings and tertiary should be kept fairly low to avoid the conditions which obtain when there is inductance in the neutral connection. When the tertiary is not designed to supply a load its capacity is determined by the heating conditions imposed by short circuits. For this reason the short-circuit conditions should be carefully investigated and full information furnished the designer.

ELECTRIFIED SUGAR MILL IN CENTRAL AMERICA

It has been decided says *Commerce Reports*, to electrify the new sugar mill of the Sula Sugar Co. at La Lima, Honduras, and plans have been drafted which will make it the largest electrified sugar mi l in Central America. Power will be developed by a 1000-kilowatt turbo-generator set with an auxiliary set of 200 kilowatts for lighting and general purposes. All the electrical equipment will be furnished by an American company and installation will be made by the same American company that is constructing the mill. The fuel to be used for running this system will be cane fodder and scraps, the supply of which is expected to be sufficient. Construction of the new mill is going forward rapidly. The boilers have been set in place and smokestacks and water towers erected. Most of the heavier machinery is also installed and the machine shop is nearly completed. The first cane will be crushed in October.

Notes on Operation of Large Interconnected Systems

BY L. L. ELDEN
Edison Electric Illuminating Co. of Boston

INTERCONNECTIONS have been made between the Boston Edison systems and the systems of the Eastern Massachusetts Electric Company and the New England Power Company, these two companies serving territory adjacent to that served by the Boston Edison Company.

Connection with the former company is effected by a 13,800-volt cable connection between nearby substations of the two companies where transmission facilities were suitable for an interchange of power. The capacity of this connection is limited to 3000 kv-a. by the capacity of the transformers installed in the Eastern Massachusetts Company's substation. The principal generating station of the Eastern Massachusetts Company being located at Salem, Mass., the connection with this station is finally completed via 22,000-volt aerial and underground lines of the E. M. E. Co. Any energy interchanged by the two companies passes through three substations on the Edison system and two substations of the E. M. E. Co., all of which supply local distribution areas.

The connection with the New England Power Company comprises a special transmission line including 25,000-volt underground transmission, 66,000-volt aerial transmission over private right of way, and two banks of step-up transformers each comprising three 5000-kv-a., three-phase, oil-cooled outdoor-type transformers. Switching facilities permit the transformers to be arranged for operation for transmission capacities of 5000 kv-a., 10,000 kv-a., and 15,000 kv-a., respectively as load requirements may dictate.

Connection is made with the N. E. P. Co. at its Clinton substation, from which 66,000-volt lines extend to the several sources of power of that company. These include not only their own hydro and steam stations, but in addition connections with the systems of a number of other public utilities and industrial corporations with which it has reciprocal arrangements for purchase or sale of power.

The physical arrangement of the interconnections with both companies is shown diagrammatically in Fig. 1.

The operation of the connection with the E. M. E. Co. has been uniformly satisfactory, barring some early difficulties initially encountered in adjusting the frequency of the two systems to the required standards and to difficulties encountered in securing suitable relay adjustments on the interconnecting lines. With the elimination of these minor troubles, no other difficulties of moment have been encountered in the daily operation of the two systems other than occasional operation of the relays to disconnect the systems when serious trouble has occurred on either which has resulted in a transfer of energy in excess of the rated capacity of the interconnection. Under normal conditions the E. M. E. Co. is the purchasing company and on several occasions the line has enabled the Boston Company to assist the E. M. E. Co. in emergencies when troubles have occurred at the latter's generating station.

In the operation of the N. E. P. Co. more difficult conditions have been encountered due to the nature and arrangement of the line connections and to the more frequent occurrence of transmission troubles incident to the large amount of 66,000-volt aerial construction exposed to lightning and other line troubles.

Violent fluctuations on both systems have occurred upon the occasion of short circuits on either, the tie line usually opening and separating the systems on such occasions. The extent to which these troubles

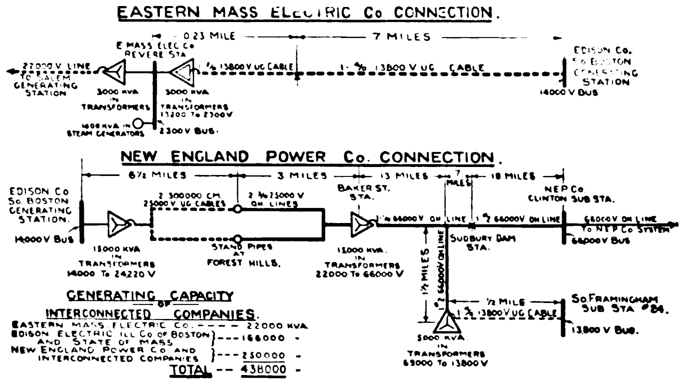

FIG. 1

have affected either system has been entirely dependent upon the generating capacity in service and load on each system at the time of trouble, and in a few cases the results have been rather serious.

Experiments with various relay adjustments have effected some relief, although it now appears that heavy shorts on either system will continue to affect the other in the future as in the past, since there appears no means readily available to eliminate such effects without unfavorably affecting the voltage regulation of the tie line.

In the initial operation of this interconnection certain difficulties developed due to variations in frequency on the N. E. P. Company's system. That company being a large purchaser of energy from companies other than the Edison Company is naturally obliged to accept some modification of standard frequency at times in order that each selling company may deliver the power required for each day's operating schedule. These variations have caused some diffi-

culty in effecting a proper division of the load between the various systems due to the desire of the Edison Company not to depart from its past practise of maintaining a standard frequency of 60 cycles at all times. This is accomplished through the use of the Warren clock for regulating purposes, and has become an important factor in the operation of the system due to the extensive use of Warren clocks as time keeping devices by the company's customers. The company has, therefore, unintentionally drifted into the undesirable position of operating a "time keeping" system which has been so satisfactory to certain users that it has been employed in some locations in place of Western Union time service.

Operation in connection with the N. E. P. Co. has caused some troubles in this direction, although, in general, time keeping errors are small and are corrected by minor changes in frequency over a given period or until normal time conditions are restored.

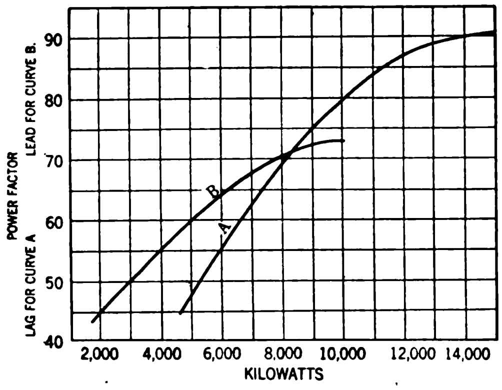

Fig. 2—Power Factor Curves of Interconnecting Transmission Line between the Edison Electric Illuminating Co. of Boston and the New England Power Co.

Curve *A*—Edison Co. supplying power to the N. E. P. Co. at the Edison South Boston Station.

Transformers at Baker St. station connected 22,000 to 66,000 volts.

Curve *B*—Edison Co. supplying power from the N. E. P. Co. at the Edison South Boston station.

Transformers at Baker St. station connected 60,000 to 22,000 volts.

The connection with the N. E. P. Co. as originally conceived was constructed for the delivery of energy to that company, there being no thought of transmitting energy in the reverse direction to the Edison Company beyond substation No. 24 at South Framingham. Variable tap connections were, therefore, provided on the step-up transformers at Baker Street Station to secure proper control of power factor and voltage regulation which have enabled us to secure the results indicated by curve *A* in Fig. 2. It later developed that the Edison Company could purchase so called "freshet power" at times from the N. E. P. Co. under favorable terms, and in accordance therewith a contract was executed for the purchase of such power for delivery during off-peak periods, or when otherwise available.

With the transformers connected for delivery of power to the N. E. P. Co. the conditions for reverse operation were very unfavorable as regards voltage regulation and control of power factor, requiring rearrangement of tap connections to change the ratio from 22,000/66,000 to 22,000/60,000 volts, this arrangement resulting in operating conditions illustrated by curve *B*, when energy is received at L Street Station or at South Framingham, station 24. This condition may be improved by the addition of taps to the high-voltage winding of transformers at L street station or at Baker Street station, the former location for the change being preferable.

To make changes in tap connections rapidly, some special operating mechanism will be required other than what is now available. Such apparatus should preferably be designed for remote control operation. Under present conditions a change in tap connections requires about eight hours and involves a considerable expense. Other methods of accomplishing the same end might include the use of induction regulators or synchronous condensers if the results accomplished would justify their use. It will be obvious that the use of either form of equipment will make it possible to materially improve curves *A* and *B* under any loading conditions, such improvement being of considerable advantage.

Like all transmission companies serving an extended area, the N. E. P. Co. in the past has had to contend with wide variations in voltage in the remote parts of its system, these in part being due to insufficient line capacity and to the effect of loads of low power factor. During the past two or three years these conditions have been materially improved by the reconstruction of certain lines and the installation of a number of synchronous condensers of large capacity at strategic points in the system where control of voltage regulation would be particularly effective. In the operation of the three systems as interconnected, no special provisions have had to be made for voltage regulation other than to provide lines of suitable capacity and suitable tap connections on step-up transformers in the tie lines to secure delivery voltages suited to loading requirements. In the case of the N. E. P. Company's connection, regulation of voltage may be accomplished to a limited extent by increasing or decreasing the number of cables and transformers in service.

The successful operation of interconnected systems appears to require only the complete cooperation of load dispatchers in control of system operation. Modification of existing methods will frequently be found effective in eliminating troubles which occur and in general a careful study of any disturbing factors will usually suggest means for relief in one form or another.

Some Transmission Line Tests

BY W. W. LEWIS

General Electric Company, Schenectady, N. Y.

IN THE MONTH of October, 1919, Mr. J. H. Foote of the Consumers Power Co., and the writer made a series of tests on the 30-cycle 140,000-volt system of that company in western Michigan. A summary of the tests for corona loss has been published.[1] There are some interesting features of these tests which were not mentioned in the previous paper, as their explanation was not clear at that time. The questions in regard to these features have now been pretty well cleared up and they will be discussed briefly in this paper.

Corona loss tests were made on a transmission line 101.5 miles long extending from Junction Dam to Grand Rapids, and some tests with an additional 47.3 miles extending from Grand Rapids to Kalamazoo. Fig. 1 shows a diagram of the system. Power for the tests was supplied by the three 6,250-kv-a., 18-pole,

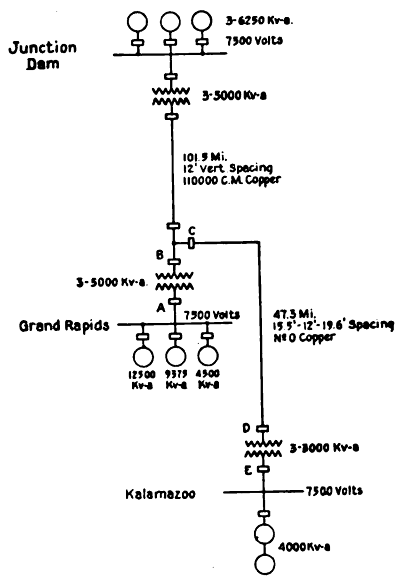

FIG. 1—DIAGRAM OF CONSUMERS POWER CO., 140,000-VOLT 30-CYCLE SYSTEM

100-rev. per min., 7,500-volt, 30-cycle waterwheel-driven generators at Junction Dam. The generators at Grand Rapids and the frequency-changer set at Kalamazoo were not in circuit, switches marked *A* and *E* being open throughout the test.

The line from Junction to Grand Rapids consists of three conductors, each of seven strands medium hard-drawn copper, total cross-section 110,000 cir. mils. The conductors are spaced practically in a vertical plane 12 ft. apart, and supported by 10-disk insulator units in suspension and 12 in strain. The height of lowest conductor at the tower is about 40 ft. and at the middle of the span about 26 ft. The tower spacing averages about 530 ft. The average elevation of the line is about 750 ft. above sea level. The direction of the line is nearly straight north and south with Junction generating station at the north end. There is one transposition tower about every 15 miles giving a complete barrel in about 45 miles. The line had been in service about one and one-half years at the time of the tests.

The line from Grand Rapids to Kalamazoo consists of No. 0 stranded copper conductor spaced 15.5, 12 and 19.6 ft. respectively, with two conductors supported on the top crossarm on opposite sides of the towers and one conductor on the middle arm of a two-circuit tower. The conductor are supported by 10-disk insulator units.

The most important tests were made on the Junction—Grand Rapids Line. The constants of this line are as follows:

Geometrical mean spacing, 181.5 inches.

Radius conductor, 0.19 inch.

Measured resistance per mile at 47.4 deg. fahr., 0.485 ohms.

Measured reactance per mile at 30 cycles, 0.409 ohms.

Measured impedance per mile at 30 cycles, 0.6345 ohms.

Calculated capacitance per mile, 0.01303 $\times 10^{-6}$ farad.

Calculated susceptance per mile at 30 cycles, 2.457 $\times$ 10^{-6} mho.

For the 101.5 miles from Junction Dam to Grand Rapids these constants become as follows:

Resistance, 49.2 ohms.

Reactance, 41.5 ohms.

Impedance, 64.4 ohms.

Capacitance, 1.322 $\times$ 10^{-6} farad.

Susceptance, 249.2 $\times$ 10^{-6} mho.

The step-up transformers at Junction and step-down transformers at Grand Rapids are similarly rated as follows: Three single-phase, water-cooled, 30-cycle, 5000-kv-a., 140,000/135,000/130,000/125,000/120,000-volt high-tension, 7500-volt low-tension, normally connected delta-delta. The tested impedance of the three transformers at Grand Rapids, based on 5000 kv-a., 7500 volts, 30 cycles and measured by applying voltage to the low-tension winding and short-circuiting the high-tension winding, averaged as follows:

7.13 per cent for the 140,000-volt winding
7.22 per cent " " 135,000 " "
7.25 per cent " " 130,000 " "
7.42 per cent " " 125,000 " "
7.55 per cent " " 120,000 " "
Average temperature 25 deg. cent.

1. *General Electric Review*, May, 1920.

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., June 21-24, 1921.

The resistance at 25 deg. cent by shop tests was 17.42 ohms for the 140-kv. winding and 0.0516 ohms for the 7500-volt winding. Excitation curves were taken on the transformers at Junction connected three-

TABLE I

TEST NO. 6. EXCITATION OF TRANSFORMER BANK AT JUNCTION CONNECTED 7500 VOLTS DELTA TO 135,000 VOLTS DELTA

Reading No.	Freq.	Volts L. V.	Amp. L. V.	Kw.	Kv-a.	Percent P. F.
1	30	3165	4.0	20	22	90.9
2	30	3640	5.0	24	31	77.4
3	30	4600	6.0	39	48	80.3
4	30	5310	7.5	50	69	72.5
5	30	5920	10.3	62	106	58.5
6	30	6200	12.6	69	135	51.1
7	30	6470	14.8	77	166	46.4
8	30	6950	20.6	89	248	35.9
9	30	7520	31.8	109	408	26.7
10	30	8000	49.4	138	684	20.2
11	30	8280	63.5	158	911	17.4
12	30	8480	79.7	178	1156	15.4

See Fig. 2.

phase, with the results shown in Table I and in Fig. 2. Fig. 3 is an oscillogram of the current and potential waves during the excitation test.

The instruments used in most of the tests were calibrated portable voltmeters, ammeters and wattmeters and calibrated potential transformers and current transformers from the Schenectady Laboratory. In some of the tests the 400:5 ampere calibrated current transformers were not of sufficient capacity so that it was necessary to use the 2000:5 ampere station current transformers. In these cases the station po-

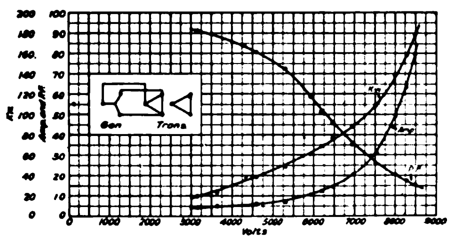

Fig. 2—Excitation Test on Bank of Three 5000-kv-a. 7500 to 140,000-Volt Transformers at Junction—Test 6

tential transformers were also used for convenience. Fig. 4 shows the connections of the instruments for the tests, the power transformers being connected at times delta-delta, and at times delta-Y as shown in the figure.

Delta Connection of Transformers

A portion of these tests was made with the line connected from Junction to Kalamazoo, and the remainder with the line from Junction to Grand Rapids (see Fig. 1). The calibrated current and potential transformers and instruments were used throughout and connected as shown in Fig. 4. In these tests, of course, the high-tension side of the power transformers was connected in delta.

The tests may be described as follows:

October 14-15, 1919:

Test No. 7. Line Junction to Kalamazoo. No transformers at Grand Rapids or Kalamazoo.

Test No. 8. Line Junction to Kalamazoo. Transformers on at Grand Rapids and Kalamazoo.

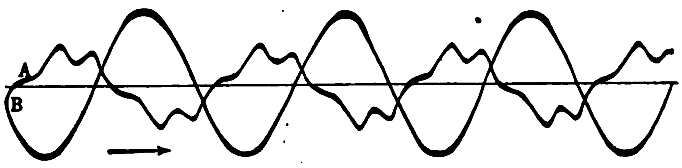

Fig. 3—Low-Voltage Current and Potential Waves During Excitation Test on Transformer Bank—Test 6

Transmission line tests at Junction Dam, Mich.
Consumers Power Company, 140-kv., 30 ~ system. Oct. 14-15, 1919.
Excitation of three 5000-kv-a. transformers at Junction.
Transmission line disconnected.
Curve A—Line current, low-voltage side.
Curve B—Potential, low-voltage side.

Test No. 9. Line Junction to Grand Rapids. Grand Rapids transformers on.

Test No. 10. Line Junction to Grand Rapids. No transformers at Grand Rapids.

October 15-16, 1919:

Test No. 11. Line Junction to Kalamazoo. No transformers at Grand Rapids or Kalamazoo.

Test No. 12. Line Junction to Kalamazoo. Kalamazoo and Grand Rapids transformers on.

Test No. 13. Line Junction to Grand Rapids. Grand Rapids transformers on.

Test No. 14. Line Junction to Kalamazoo. Kalamazoo transformers on, Grand Rapids transformers off.

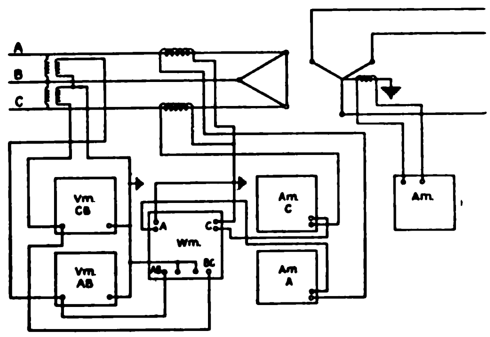

Fig. 4—Diagram Showing Connection of Instruments for Corona Tests

Test No. 15. Line Junction to Grand Rapids. No transformers at Grand Rapids.

October 16-17, 1919:

Test No. 17. Line Junction to Grand Rapids. Grand Rapids transformers on.

Test No. 19. Line Junction to Grand Rapids. No transformers at Grand Rapids.

The data are tabulated in Tables II to XII inclusive, and plotted in Figs. 5 to 8 inclusive.

The readings were corrected as follows: Based on the laboratory calibration curves, made in September

TABLE II

TEST NO. 10. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. NO TRANSFORMERS AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
44	30	4140	74.6	205	11.4	56	1470	3.78
45	30	5205	93.8	254	14.1	91	2300	3.96
46	30	5700	102.7	275	15.3	109	2720	3.98
47	30	6100	109.8	292	16.2	142	3090	4.57
48	30	6600	118.8	313	17.4	184	3580	5.15
49	30	7120	128.1	328	18.2	346	4045	8.54
50	30	7555	136.0	340	18.9	514	4450	11.55
51	30	8115	146.0	344	19.1	1051	4835	21.73
52	30	8610	155.0	364	20.2	1700	5425	31.32
53	30	8920	160.5	357	19.8	2165	5520	39.21

Transformer Ratio 135000 : 7500 = 18 : 1
Date..........................Oct. 15, 1919
Barometer.....................29.34 in.
Temperature...................44.7 deg. fahr.
Humidity......................91.4 per cent.
Weather.......................Clear
See Fig. 5.

TABLE III

TEST NO. 15. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. NO TRANSFORMERS AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
37	30	4700	84.6	227	12.6	66	1850	3.6
38	30	5220	94.0	253	14.1	87	2290	3.8
39	30¼	5605	101.0	270	15.0	114	2620	4.4
40	30	6130	110.4	293	16.3	250	3110	8.0
41	30	6680	120.2	315	17.5	538	3670	14.7
42	30	7210	129.8	338	18.8	866	4220	20.5
44	30	7990	143.8	372	20.7	1558	5150	30.3
45	30	8500	153.0	382	21.2	2030	5620	36.1
46	30	9010	162.1	382	21.2	2690	5960	45.1

Transformer Ratio 135000 : 7500 = 18 : 1
Date..........................Oct. 16, 1919
Barometer.....................29.38 in.
Temperature...................43.9 deg. fahr.
Humidity......................94.4 per cent.
Weather.......................Rainy.
See Fig. 5.

TABLE IV

TEST NO. 18. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. NO TRANSFORMERS AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
13	30	4320	77.8	209	11.6	53	1565	3.4
14	30	5060	91.1	242	13.4	70	2120	3.3
15	30	5775	103.9	274	15.2	88	2740	3.2
16	30	6340	114.1	297	16.5	105	3260	3.2
18	30	6980	125.6	318	17.7	157	3840	4.1
19	30	7560	136.0	334	18.6	270	4430	6.1
20	30	8160	146.9	340	18.9	805	4805	16.8
21	30	8500	153.0	338	18.8	1230	4980	24.7
22	30	8800	158.4	333	18.5	1600	5080	31.5

Transformer Ratio 135000 : 7500 = 18 : 1
Date..........................Oct. 17, 1919
Barometer.....................29.40 in.
Temperature...................34.7 deg. fahr.
Humidity......................91.0 per cent.
Weather.......................Clear
See Fig. 5.

TABLE V

TEST NO. 9. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. TRANSFORMERS ON AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
33	30	4140	74.6	194	10.8	84	1392	6.0
34	30	4480	80.7	211	11.7	101	1638	6.2
35	30	5250	94.6	243	13.5	142	2210	6.4
36	30	5665	102.0	257	14.3	162	2522	6.4
37	30	6170	111.0	274	15.2	188	2928	6.4
38	30	7000	126.0	279	15.5	336	3383	9.4
39	30	7640	137.5	258	14.3	605	3416	17.7
40	30	8080	145.4	218	12.1	964	3052	31.6
41	30	8555	154.0	188	10.4	1548	2786	55.6
42	30	8655	155.8	169	9.4	1730	2533	68.3
43	30	8950	161.1	157	8.7	2090	2433	85.9

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Grand Rapids Transformer Ratio 125000 : 7500
Date..........................Oct. 15, 1919
Barometer.....................29.34 in.
Temperature...................46.7 deg. fahr.
Weather.......................Clear
See Fig. 6.

TABLE VI

TEST NO. 13. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. TRANSFORMERS ON AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
20	30	4550	82.0	213	11.8	125	1679	7.5
21	30	5130	92.4	238	13.2	151	2114	7.1
22	30	5540	99.8	253	14.1	168	2428	6.9
23	30	6095	109.6	270	15.0	247	2850	8.7
24	30	6795	122.3	282	15.7	594	3320	17.9
25	30	7580	136.5	278	15.4	1225	3650	33.6
26	30	8070	145.3	273	15.2	1610	3818	42.2
27	30	8480	152.6	228	12.7	2082	3350	62.2

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Grand Rapids Transformer Ratio 125000 : 7500
Date..........................Oct. 16, 1919
Barometer.....................29.38 in.
Temperature...................46.2 deg. fahr.
Humidity......................93.6 per cent.
Weather.......................Rainy
See Fig. 6.

TABLE VII

TEST NO. 17. CORONA LOSS TEST. LINE FROM JUNCTION TO GRAND RAPIDS. TRANSFORMERS ON AT GRAND RAPIDS

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
3	30	4530	81.6	212	11.8	87	1665	5.2
4	30	4680	84.3	220	12.2	87	1785	4.9
5	30	5625	101.3	263	14.6	131	2560	5.1
6	30	6090	109.6	280	15.6	166	2950	5.6
7	30	6620	119.2	297	16.5	192	3410	5.6
8	30	7000	126.0	303	16.8	235	3670	6.4
9	30	7620	137.2	308	17.1	384	4070	9.4
10	30¼	8070	145.3	296	16.4	736	4140	17.8
11	30	8600	154.8	253	14.1	1358	3770	36.0
12	30	8900	160.2	229	12.7	1806	3530	51.2

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Grand Rapids Transformer Ratio 140000 : 7500
Date..........................Oct. 17, 1919
Barometer.....................29.4 in.
Temperature...................33.5 deg. fahr.
Humidity......................89.0 per cent.
Weather.......................Clear
See Fig. 6.

TABLE VIII

TEST NO. 7. CORONA LOSS TEST.
LINE FROM JUNCTION TO KALAMAZOO
NO TRANSFORMERS AT GRAND RAPIDS OR KALAMAZOO

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
13	29.5	4080	73.4	289	16.0	85	2040	4.17
14	30	4400	79.2	313	17.4	89	2388	3.73
15	29.5	5170	93.1	373	20.7	155	3340	4.64
16	30	5470	98.5	389	21.6	168	3680	4.57
17	30	5880	105.8	423	23.5	189	4310	4.39
18	30	6440	116.0	457	25.4	274	5100	5.38
19	30	6900	124.2	493	27.4	418	5890	7.10
20	30	7280	131.0	524	29.1	656	6610	9.93
21	30	7840	141.1	570	31.7	1510	7740	19.51
21A		7930	142.7	578	32.1	1672	7940	21.08
22		8110	146.0	588	32.7	1880	8260	22.78
23	30	8450	152.1	618	34.3	2615	9050	28.90

Transformer Ratio = 135000 : 7500 = 18 : 1
Date..........................Oct. 15, 1919
Barometer....................29.32 in.
Temperature..................51.0 deg. fahr.
Humidity.....................83.9 per cent.
Weather......................Clear
See. Fig. 7.

TABLE IX

TEST NO. 11. CORONA LOSS TEST.
LINE FROM JUNCTION TO KALAMAZOO
NO TRANSFORMERS AT GRAND RAPIDS OR KALAMAZOO

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
1	30	4450	80.2	315	17.5	86	2428	3.46
2	30¼	5310	95.6	380	21.1	157	3498	4.49
3	30	5755	103.6	415	23.1	248	4140	5.99
4	30	6380	114.8	455	25.3	470	5030	9.35
5	30¼	6980	125.6	494	27.5	863	5975	14.45
6	30	7480	134.6	546	30.3	1345	7080	19.00
7	30	8060	145.0	586	32.6	2275	8180	27.80
8	30	8480	152.6	609	33.8	3030	8950	33.88
9	30	8780	158.0	622	34.6	3590	9460	37.96

Transformer Ratio 135000 : 7500 = 18 : 1
Date..........................Oct. 16, 1919
Barometer....................29.38 in.
Temperature..................46.0 deg. fahr.
Humidity.....................96.8 per cent.
Weather......................Rainy
See Fig. 7.

TABLE X

TEST NO. 8. CORONA LOSS TEST.
LINE FROM JUNCTION TO KALAMAZOO
TRANSFORMERS ON AT GRAND RAPIDS AND KALAMAZOO

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
24	30.3	4100	73.8	291	16.2	139	2067	6.73
25	30.5	4530	81.6	319	17.7	171	2502	6.83
26	30	5220	94.0	351	19.5	245	3174	7.72
27	30	5720	103.0	368	20.4	270	3647	7.41
28	30	6260	112.6	385	21.4	400	4175	9.58
29	30	6775	121.9	382	21.2	512	4480	11.43
30	30	7160	128.9	362	20.1	658	4490	14.65
31	30	7500	135.0	327	18.2	874	4250	20.57
32	30	7860	141.5	274	15.2	1195	3730	32.04

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Grand Rapids Transformer Ratio 125000 : 7500
Kalamazoo Transformer Ratio 120000 : 7500
Date..........................Oct. 15, 1919
Barometer....................29.32 in.
Temperature..................47.9 deg. fahr.
Humidity.....................90.2 per cent.
Weather......................Clear
See. Fig. 8.

TABLE XI

TEST NO. 12. CORONA LOSS TEST.
LINE FROM JUNCTION TO KALAMAZOO
TRANSFORMERS ON AT GRAND RAPIDS AND KALAMAZOO

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
10	30	4540	81.8	316	17.6	164	2487	6.6
11	30	5135	92.4	349	19.4	227	3103	7.3
12	30	5530	99.6	370	20.6	267	3544	7.5
13	30	6220	112.0	392	21.8	477	4222	11.3
14	30	6700	120.6	397	22.0	796	4610	17.3
15	30	7060	127.1	395	21.9	1058	4830	21.9
16	30	7520	135.4	381	21.2	1516	4960	30.6
17	30	8070	145.2	343	19.1	2280	4798	47.5
18	30	8480	152.6	301	16.7	2970	4420	67.2
19	30	8660	156.0	287	15.9	3430	4310	79.6

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Grand Rapids Transformer Ratio 125000 : 7500
Kalamazoo Transformer Ratio 130000 : 7500
Date..........................Oct. 16, 1919
Barometer....................29.38 in.
Temperature..................46.7 deg. fahr.
Humidity.....................94.2 per cent.
Weather......................Rainy
See Fig. 8.

TABLE XII

TEST NO. 14. CORONA LOSS TEST.
LINE FROM JUNCTION TO KALAMAZOO
KALAMAZOO TRANSFORMERS ON. GRAND RAPIDS TRANSFORMERS OFF.

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Percent P. F.
28	30	4440	80.0	313	17.4	115	2410	4.8
29	30	5180	93.3	361	20.1	177	3240	5.5
30	30	5600	100.8	385	21.4	233	3740	6.2
31	30	6080	109.4	411	22.8	329	4330	7.6
32	30	6640	119.5	438	24.3	705	5040	14.0
33	30	7160	128.9	457	25.4	1160	5670	20.5
34	30	7480	134.6	464	25.8	1495	6010	24.9
35	30	8010	144.2	476	26.5	2200	6600	33.3
36	30	8500	153.0	486	27.0	3110	7160	43.4

Transformer Ratio = 18 : 1
Junction Transformer Ratio 135000 : 7500
Kalamazoo Transformer Ratio 130000 : 7500
Date..........................Oct. 16, 1919
Barometer....................29.38 in.
Temperature..................46.2 deg. fahr.
Humidity.....................93.6 per cent.
Weather......................Rainy
See. Fig. 8.

and October before the tests and in November after the tests, average voltmeter, ammeter and wattmeter constants, combining both the instrument and instrument transformer corrections, were evolved. The wattmeter readings were corrected for phase angle in the following manner: The phase angles for the current transformers and potential transformers were obtained from the calibration curves, and a constant phase angle of three minutes assumed for the wattmeter. The apparent power factor was found from the kw. and kv-a. as given by the corrected instrument readings, and the angle θ_2 was found from this power factor. The total phase angle for the instrument transformers and wattmeters was added to θ_2 to give the true angle θ.

The cosine of θ gives the true power factor. The ratio $\cos\theta / \cos\theta_2$ is the correction factor by which the apparent kilowatts are multiplied to give the true kilowatts. This correction factor is greater than one for leading currents and less than one for lagging

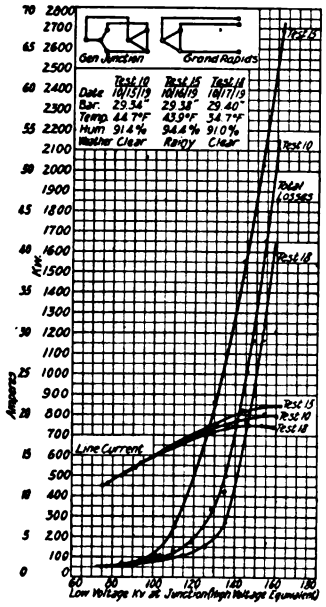

FIG. 5—CORONA LOSS, TESTS 10, 15 AND 18—LINE FROM JUNCTION TO GRAND RAPIDS—NO TRANSFORMERS AT GRAND RAPIDS

currents. The correction factor varies from 5 to 13 per cent at the lower values and from 0.2 to 2 per cent at the higher values. It must be understood that in any event the corrections are approximate. The

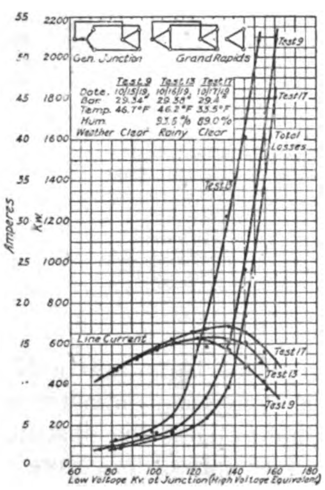

FIG. 6—CORONA LOSS, TESTS 9, 13 AND 17—LINE FROM JUNCTION TO GRAND RAPIDS—TRANSFORMERS ON AT GRAND RAPIDS

values of kilowatts and power factor given in the tables are corrected values found by this method.

Discussion of Results. Fig. 6 gives a comparison of the losses on the line from Junction to Grand Rapids, with transformers connected at Grand Rapids, under clear and rainy conditions and under clear conditions

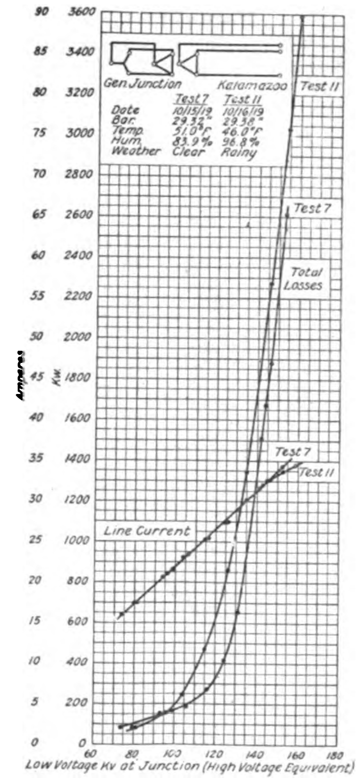

FIG. 7—CORONA LOSS, TESTS 7 AND 11—LINE FROM JUNCTION TO KALAMAZOO—NO TRANSFORMERS ON AT GRAND RAPIDS OR KALAMAZOO

with two degrees of temperature. The effect of increase of temperature and of rain in increasing the

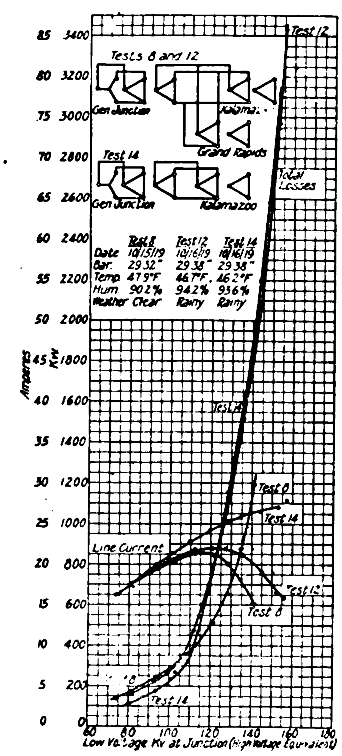

FIG. 8—CORONA LOSS, TESTS 8, 12 AND 14—LINE FROM JUNCTION TO KALAMAZOO—TESTS 8 AND 12, TRANSFORMERS ON AT GRAND RAPIDS AND KALAMAZOO—TEST 14, TRANSFORMERS ON AT KALAMAZOO ONLY

losses is well illustrated. The curves also show the effect of exciting current of the transformers at Grand Rapids, at the higher densities, in decreasing the line current at Junction.

Fig. 5 shows similar curves on the Junction-Grand Rapids line with the transformers at Grand Rapids not connected to the line. The loss curves, it will be noted, practically coincide with those of Fig. 6 except at the lower end, where the loss is nearly all

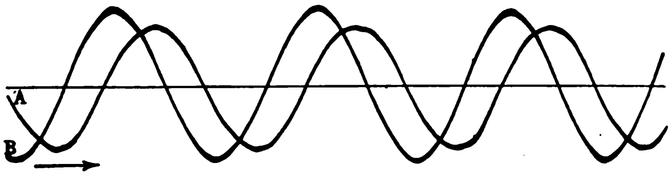

Fig. 9—Low-Voltage Current and Potential Waves Taken During Test 7

Transmission line tests at Junction Dam, Mich.
Consumers Power Company, 140-kv., 30 ~ system. Oct. 14-15, 1919.
Corona test at 135 kv., line, Junction to Kalamazoo.
No transformer on at Grand Rapids or Kalamazoo.
Curve A—Line current, low-voltage side.
Curve B—Potential, low-voltage side.

due to the transformers. The line current does not have the marked tendency to droop apparent in Fig. 6, owing to the abscence of the Grand Rapids transformer bank.

Figs. 7 and 8 show curves of losses of the line from Junction to Kalamazoo, the former with no transformers on at the end and the latter with transformers connected.

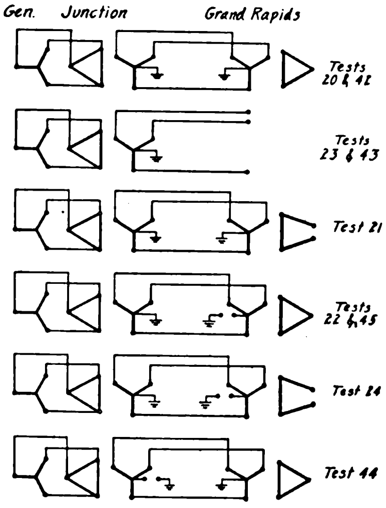

Fig. 10—Diagram of Connections of Power Transformers During Corona Tests with High-Tension Side of Transformers Y-Connected

The loss curves of Tests Nos. 12 and 14 are practically identical, except at the lower portion, where the additional loss of the transformers at Grand Rapids in Test No. 12 raises the curve above that of Test No. 14. The effect of the transformers is also seen in the line current curves.

An oscillogram of typical low-tension waves taken during these tests is reproduced in Fig. 9.

Y-Connection of Transformers

The Y-connected tests were made with the Junction-Grand Rapids line only. In some tests the transformer bank at Grand Rapids was connected to the circuit and in some cases omitted. In all cases the neutral either at Junction or Grand Rapids, and sometimes both, was grounded.

The following tests were made:

October 19, 1919:

Test No. 20. Line Junction to Grand Rapids. Grand Rapids transformers on. Neutrals grounded at Junction and Grand Rapids.

Test No. 21. Low-voltage delta open at Grand Rapids.

Test No. 22. Low-voltage delta closed at Grand Rapids. Neutral isolated at Grand Rapids.

Test No. 23. Grand Rapids transformers disconnected from line.

Test No. 24. Grand Rapids transformers on. Delta open and neutral isolated at Grand Rapids.

October 26, 1919:

Test No. 42. Line Junction to Grand Rapids. Grand Rapids transformers on. Neutrals grounded at Junction and Grand Rapids.

Test No. 43. Grand Rapids transformers disconnected from line.

Test No. 44. Grand Rapids transformers on. Neutral grounded at Grand Rapids. Neutral isolated at Junction.

Test No. 45. Grand Rapids transformers on. Neutral grounded at Junction. Neutral isolated at Grand Rapids.

The various connections are illustrated in Fig. 10, and the results of the tests are given in Tables XIII to XXI inclusive.

Although we have calibration curves for the various instruments we do not have such curves for the station potential and current transformers. It was

TABLE XIII

TEST NO. 23. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS.
NO TRANSFORMERS AT GRAND RAPIDS.
NEUTRAL GROUNDED AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
24	30	3930	109.0	476	17.2	48	3240	1.48	0
25	30	4550	126.2	548	19.8	72	4320	1.67	0
26	30	5060	140.4	616	22.2	480	5400	8.89	1.25
27	30	5680	157.6	752	27.1	2230	7400	30.13	7.50
28	30	6280	174.2	924	33.3	4030	10050	40.1	13.3
29	30	6710	186.1	1048	37.8	5380	12180	44.2	16.5
30	30	7150	198.4	1200	43.2	6960	14860	46.8	19.0

Amp. Neutral begin at 138500 volts
Transformer Ratio = 120000/208000 Y : 7500 = 27.73 : 1
Date........................Oct. 19, 1919
Barometer...................29.62 in.
Temperature.................48.8 deg. fahr.
Humidity....................61.4 per cent.
Weather.....................Clear
See Fig. 11.

TABLE XIV

TEST NO. 43. CORONA LOSS TEST.
LINE JUNCTION TO GRAND RAPIDS.
NO TRANSFORMERS AT GRAND RAPIDS.
NEUTRAL GROUNDED AT JUNCTION.

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
15	30	3350	93.0	420	15.1	48	2440	1.97	0
16	30	4040	112.0	508	18.3	48	3350	1.35	0
17	30	4600	127.6	576	20.8	72	4590	1.57	0
18	30	5020	139.2	632	22.8	648	5580	11.71	2.8
19	30	5680	157.5	772	27.8	2330	7600	30.65	8.8
20	30	5900	163.6	820	29.6	2880	8380	34.4	10.5
21	30	6690	185.5	1032	37.2	5305	11960	44.3	15.9
22	30	7160	198.5	1176	42.4	6840	14590	46.9	18.8

Amp. Neutral begin at 127500 volts
Amp. Neutral 1 amp. at 133600 volts
Transformer Ratio = 120000/208000Y : 7500 = 27.73 : 1
Date........................Oct. 26, 1919
Barometer....................29.38 in.
Temperature..................42.5 deg. fahr.
Humidity.....................81.0 per cent.
Weather......................Cloudy
See Fig. 11.

TABLE XV

TEST NO. 20. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS
TRANSFORMERS ON AT GRAND RAPIDS
NEUTRALS GROUNDED AT JUNCTION AND GRAND RAPIDS
READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
1	30	3840	106.5	452	16.3	72	3010	2.39	0
2	30	4420	122.6	528	19.0	120	4040	2.97	0
3	30	5060	140.4	592	21.3	480	5180	9.27	0
4	30	5580	154.8	720	25.9	1945	6960	27.94	2.0
5	30	5900	163.6	816	29.4	2930	8340	35.14	4.5
6	30	6740	187.0	1072	38.6	5545	12520	44.29	6.5
7	30	7300	202.5	1220	44.0	7440	15430	48.20	7.5
8	30	7500	208.0	1272	45.9	8160	16530	49.38	8.25

Transformer Ratio = 120000/208000 Y : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts L. V.	Kv. H. V. by ratio	Amp. neut.
1	3600	116.4	0
2	4120	133.2	0
3	4720	152.6	0
4	5160	166.9	3.0
5	5480	177.2	4.5
6	6240	201.8	6.0
7	6780	219.2	6.9
8	6940	224.3	7.3

Transformer Ratio = 140000/242500 Y : 7500 = 32.33 : 1
Date..........................Oct. 19, 1919
Barometer......................29.64 in.
Temperature....................51.1 deg. fahr.
Humidity.......................53.1 per cent.
Weather........................Clear, sunshiny.
See Fig. 12.

TABLE XVI

TEST NO. 42. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS
TRANSFORMERS ON AT GRAND RAPIDS
NEUTRALS GROUNDED AT JUNCTION AND GRAND RAPIDS

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
5	30	3950	109.5	460	16.6	72	3150	2.29	0
6	30	4950	127.4	520	18.8	168	4135	4.06	0.15
7	30	4975	138.0	560	20.2	528	4830	10.93	0.88
9	30	5480	152.0	680	24.5	1775	6460	27.5	2.90
10	30	6160	170.9	896	32.3	3650	9560	38.2	4.90
12	30	6520	181.0	1000	36.1	4750	11290	42.1	5.72
13	30	7100	197.0	1152	41.5	6645	14170	46.9	7.11
14	30	7510	208.2	1252	45.1	7970	16290	48.9	8.00

Transformer Ratio = 120000/208000 Y : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts L. V.	Kv. H. V. by ratio	Amp. neut.
5	3780	109.1	0
6	4500	129.9	0
7	4800	138.5	0.6
9	5520	159.4	2.4
10	6180	178.4	4.5
12	6540	188.7	5.4
13	7140	206.0	6.72
14	7560	218.2	7.5

Transformer Ratio = 125000/216500 Y : 7500 = 28.87 : 1
Date..........................Oct. 26, 1919
Barometer.....................29.32 in.
Temperature...................41 deg. fahr.
Humidity......................93.6 per cent.
Weather.......................Cloudy
See Fig. 12.

TABLE XVII

TEST NO. 21. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS.
TRANSFORMERS ON AT GRAND RAPIDS
NEUTRALS GROUNDED AT JUNCTION AND GRAND RAPIDS
DELTA OPEN AT GRAND RAPIDS

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
18	30	4385	121.6	524	18.9	72	3980	1.8	0
19	30	6070	168.4	884	31.9	3580	9300	38.5	13.5
20	30	7300	202.6	1216	43.9	7680	15390	49.9	22.0

Neutral Current Begins at 133200 volts.
Transformer Ratio 120000/208000Y : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts L. V.	Kv. H. V. by ratio	Volts open delta
18	4080	132.0	0
19	5640	182.4	0
20	6780	219.2	600

Transformer Ratio 140000/242500 : 7500 = 32.33 : 1
Date..........................Oct. 19, 1919
Barometer.....................29.62 in.
Temperature...................54 deg. fahr.
Humidity......................53.8 per cent.
Weather.......................Clear, sunshiny

TABLE XVIII

TEST NO. 22. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS
TRANSFORMERS ON AT GRAND RAPIDS.
NEUTRAL GROUNDED AT JUNCTION.
NEUTRAL ISOLATED AT GRAND RAPIDS

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
21	30	4672	129.6	572	20.6	192	4630	4.15	0.5
22	30	6006	166.6	896	32.3	3360	9320	36.04	12.0
23	30	7390	205.0	1244	44.8	7970	15920	50.05	20.5

Neutral Current Begins at 126,500 volts
Transformer Ratio = 120000/208000Y : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts neutral
21	4440
22	5640
23	6900

Transformer Ratio Grand Rapids 140000/242500Y = 32.33 : 1
Date............................Oct. 19, 1919
Weather........................Clear, sunshiny

TABLE XIX

TEST NO. 45. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS
TRANSFORMERS ON AT GRAND RAPIDS.
NEUTRAL GROUNDED AT JUNCTION
NEUTRAL ISOLATED AT GRAND RAPIDS

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
1	30	4470	124.0	544	19.6	96	4210	2.3	0
2	30	5040	139.8	620	22.4	528	5410	9.8	2.25
3	30	5575	154.5						7.50
4	30	5640	156.4	732	26.4	2136	7150	29.9	8.15
5	30	6030	167.2	832	30.0	3360	8690	38.7	11.50

Neutral Current Begins at 136,000 volts
Transformer Ratio 120000/208000 : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts neutral to ground
1	0
2	0
3	0
4	1800
5	3000

Transformer Ratio 125000/216500Y : 7500 = 28.87 : 1

TABLE XX

TEST NO. 24. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS
TRANSFORMERS ON AT GRAND RAPIDS
NEUTRAL GROUNDED AT JUNCTION
DELTA OPEN AND NEUTRAL ISOLATED AT GRAND RAPIDS

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Amp. Neut.
39	30	4360	120.9	520	18.8	72	3930	1.83	0
40	30	5080	140.9	612	22.1	552	5385	10.25	1.25
41	30	5470	151.7	680	24.5	1584	6440	24.6	6.0
42	30	5980	165.9	820	29.6	3070	8500	36.1	10.5

Transformer Ratio = 120000/20800 Y = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts L. V.	Kv. H. V. by ratio	Volts open delta	3rd Harm. per leg L. V.	3rd Harm. per leg H. V. by ratio	Fund per leg L. V.	Fund per leg H. V. by ratio
39	5160	136.8	6120	2040	34000	4740	79000
40	5880	147.0	8820	2940	49000	5095	84900
41	6300	157.0	9540	3180	53000	5435	90600
42	6960	172.7	10680	3560	59400	5980	99700
....	7980	194.5	12845	4282	71400	6730	112200
....	8520	209.0	13500	4500	75000	7235	120600

Transformer Ratio = 125000/216500 Y : 7500 = 28.87 : 1
Date............................Oct. 19, 1919
Barometer......................29.62 in.
Temperature....................42.1 deg. fahr.
Humidity.......................73.2 per cent.
Weather........................Clear, sunshiny.

TABLE XXI

TEST NO. 44. CORONA LOSS TEST.
LINE FROM JUNCTION TO GRAND RAPIDS.
TRANSFORMERS ON AT GRAND RAPIDS.
NEUTRAL GROUNDED AT GRAND RAPIDS.
NEUTRAL ISOLATED AT JUNCTION

READINGS AT JUNCTION

Reading No.	Freq.	Volts L. V.	Kv. H. V. by ratio	Amp. L. V.	Amp. H. V. by ratio	Kw.	Kv-a.	Per-cent P. F.	Volts Neut. to ground
1	30	5160	143.0	580	20.9	840	5185	16.2	500
2	30	5650	156.7	728	26.2	2208	7120	31.0	2700
3	30	6180	171.4	864	31.1	3720	9250	40.2	3850

Transformer Ratio 120000/208000Y : 7500 = 27.73 : 1

READINGS AT GRAND RAPIDS

Reading No.	Volts L. V.	Kv. H. V. by ratio	Amp. neut.
1	5160	149.0	1.8
2	5760	166.4	8.7
3	6600	190.5	11.7
	7800	225.0	12.9

Transformer Ratio 125000/216500Y : 7500 = 28.87 : 1
Date............................Oct. 26, 1919.
Barometer......................29.38 in.
Temperature....................42.5 deg. fahr.
Humidity.......................81 per cent.
Weather........................Cloudy

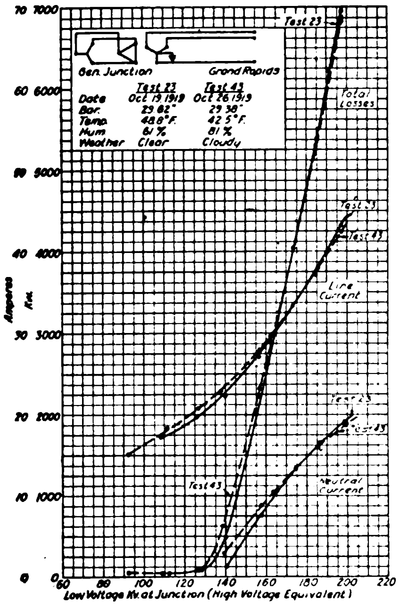

Fig. 11—Corona Loss, Tests 23 and 43—Line From Junction to Grand Rapids—No Transformers at Grand Rapids—Neutral Grounded at Junction

thought best, therefore, to give the readings uncorrected rather than to correct for the instruments only. In general the instrument corrections and instrument transformer ratios tend to reduce the readings while the phase angle corrections of the instrument transformers tend to increase them. In respect to current and potential therefore the results may be somewhat high while in respect to watts they are probably somewhat low. The corrections are not large, except at the lower readings where they are sometimes appreciable.

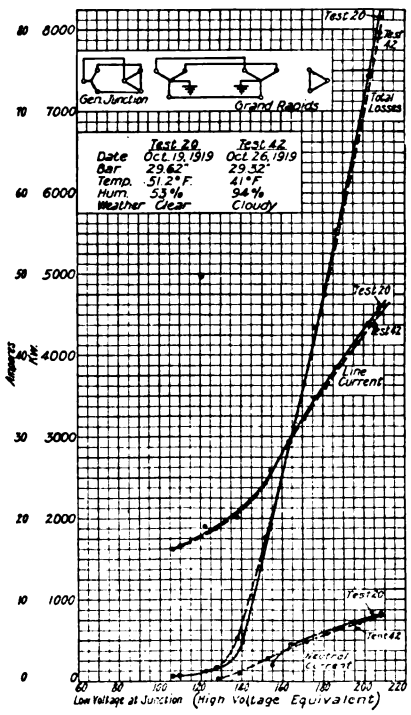

Fig. 12—Corona Loss, Tests 20 and 42—Line From Junction to Grand Rapids—Transformers on at Grand Rapids—Neutral Grounded at Grand Rapids and Junction

Corona loss, amperes line and amperes neutral for Tests 23 and 43 are plotted in Fig. 11 and for Tests 20 and 42 in Fig. 12. The results for the other tests are not plotted, but they follow very closely the plotted curves. In Fig. 13 is plotted the power factor for Test 20, also a comparison of the potentials at Junction and Grand Rapids.

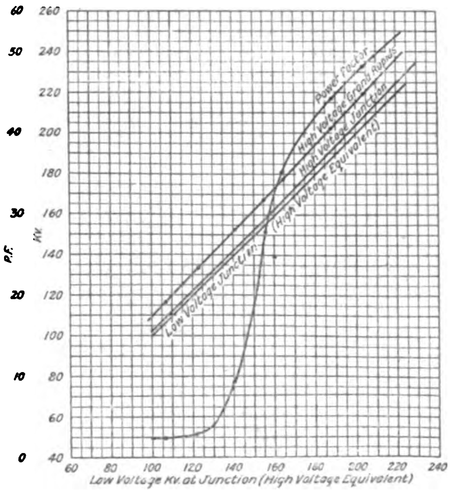

Fig. 13—Comparison of Potentials at Junction and Grand Rapids, Test 20

Discussion of Results. In these tests an ammeter was placed in the neutral ground, or if the neutral was open a voltmeter was placed between the neutral and ground. In some cases it was necessary to use a current transformer in the neutral ground and in some cases the current was read directly. In measuring the neutral voltage a potential transformer was used in all cases.

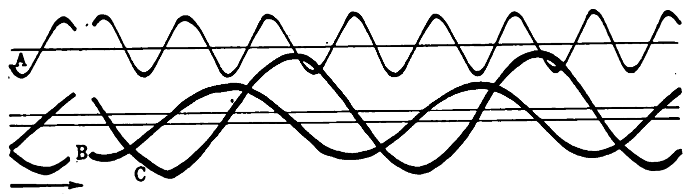

Fig. 14—Low-Voltage Current and Potential and Current in Grounded Neutral, Test 23

Transmission line tests at Junction Dam, Mich.
Consumers Power Company, 140-kv., 30 ~ system. Oct. 19, 1919.
Corona test at 198 kv., line, Junction to Grand Rapids.
No transformer at Grand Rapids. Neutral grounded at Junction.
Curve A—Current in neutral ground.
Curve B—Current in transmission line.
Curve C—Voltage across transmission line transformers.

Figs. 14 and 15 show low-voltage waves of potential and current and high-voltage waves of ground current for Tests 23 and 20 respectively. Fig. 16 shows the potential between neutral and ground for Test 44. The oscillograms show that both the neutral voltage and current are of triple frequency. There are two explanations for this, one advanced by the writer and one by Mr. F. W. Peek. The writer's explanation is as follows:

In the low-tension delta of the transformer bank there is a triple-frequency circulating current which is required by the magnetization of the iron of the transformers. This current is forced through the impedance of the windings by a small voltage which multiplied by the ratio, is reproduced in the high-voltage windings. This voltage impressed between conductors and ground charges the capacitance of the transmission conductors to ground, the charging current of the three conductors in multiple flowing back through the grounded neutral. The action is much the same as for a Y-Y transformer bank with grounded neutral, except that the voltage involved is much smaller.

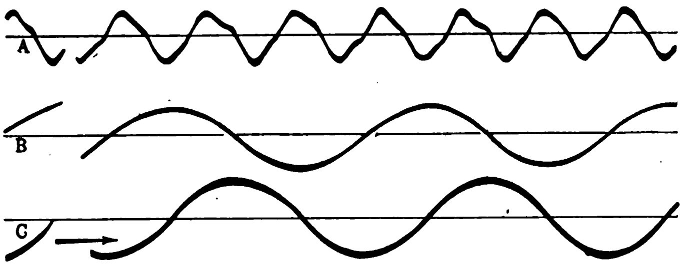

Fig. 15—Low-Voltage Current and Potential and Current in Grounded Neutral, Test 20

Transmission line tests at Junction Dam, Mich.
Consumers Power Company, 140-kv., 30 ~ system. Oct. 19, 1919.
Corona test at 208 kv., line, Junction to Grand Rapids.
Grand Rapids transformers on neutral grounded at Junction and Grand Rapids.
Curve A—Current in neutral ground.
Curve B—Current in transmission line.
Curve C—Voltage across transmission line transformers.

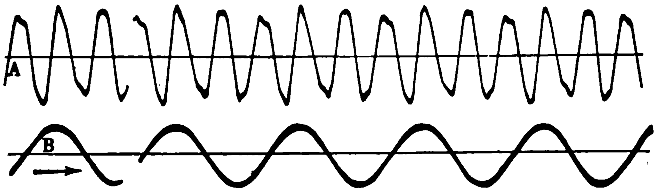

Fig. 16—Low-Voltage Potential and Potential from Neutral to Ground, Test 44

Transmission line tests at Junction Dam, Mich.
Consumers Power Company, 140-kv., 30 ~ system. Oct. 26, 1919.
Corona test at 155 kv., line, Junction to Grand Rapids.
Grand Rapids transformers on neutral open at Junction, neutral grounded at Grand Rapids.
Curve A—Voltage, neutral to ground.
Curve B—Voltage bus side of 7500-volt switch.

Mr. Peek ascribed this triple-frequency ground current to the corona, the theory being as follows:

The corona starts at a point well up on the ascending part of the voltage wave, and disappears when the wave has passed through a maximum and reached the same value on the descending portion. This occurs every half-cycle and has the effect of placing a pulsation or harmonic in the voltage wave. The pulsation may be of any odd frequency depending on the point at which the corona starts. Naturally the third harmonic being the first harmonic encountered and being in phase in all three legs, is the most conspicuous. This triple-frequency voltage, acting on the capacitance of the system, which itself is pulsating on account of the increase and decrease of diameter of the conductor due to corona, causes a triple-frequency charging current to flow through the capacitance to ground and back through the grounded neutral.

Mr. Peek has made some laboratory tests, which show conclusively that the greater part of this ground current is due to corona, in accordance with his theory, and that only a small portion of it may be ascribed to the triple-frequency magnetization of the transformers, as suggested by the writer. This greatly relieves the situation as it places the onus for this ground current on the corona, which may be avoided and not on the transformer magnetization which is unavoidable. Mr. Peek will describe his theory and tests in detail in a paper at this meeting.

The tests show that with open line and one neutral grounded the ground current is from 20 per cent to 40 per cent of the line current at corresponding voltage. With neutral grounded at both ends (and low-tension deltas closed) the neutral current at each end is from 10 per cent to 20 per cent of the line current, the current splitting in this case between the two ends. With transformers at both ends of the line but neutral grounded at one end only (Test 22), or with transformers at both ends of the line and both neutrals grounded, but the delta open at the receiving end (Test 21), the neutral current at the generating station is practically the same as when the line is open at one end.

With transformers at both ends and the neutral at one end only grounded, a voltage exists between the isolated neutral and ground as shown in Fig. 16.

It will be noted that the neutral current begins abruptly in the neighborhood of 140 kv., which means that at lower voltage the current was so small as to give no indication on the ammeter. Thus with the transmission line operating at normal voltage, the ground current will be negligible, and no trouble should be experienced from it.

Rise in Voltage. The power factor in the tests varies from 2 to 50 per cent leading. We would naturally expect a boost in voltage, due to this leading current passing through the reactance of the transformers and transmission line. Fig. 13 shows the voltage rise along the line for Test 20. The rise through the transformers was calculated. The voltage at the Grand Rapids end of the line was measured on the low-tension side, and the high-tension voltage is this measured voltage multiplied by the ratio, as there is no current passing through the transformers and therefore no change in voltage. The calculated rise in voltage along the line is considerably less than the measured rise.

The tests with open line (Grand Rapids transformers connected), Tests Nos. 23 and 43, should give

a greater rise than the tests with transformers at the end of the line. The calculated rise with open line, however, is much less than measured with transformers at the end of the line.

These discrepancies may be caused by change in capacitance due to corona, or by harmonics introduced by corona, which will be discussed later.

Open Delta. In Test No. 21 the transformers were on at Grand Rapids, with neutrals grounded at Junction and Grand Rapids. The low-tension delta was open at Grand Rapids. A voltmeter placed across the corner of the open delta read about 600 volts with 203 kv. at Junction.

In Test No. 24, in addition to having the low-tension delta open, the high-voltage neutral was isolated at Grand Rapids. Now a voltage was read

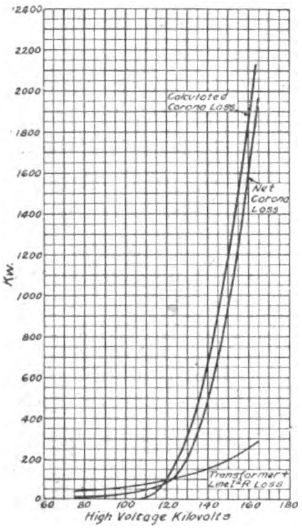

FIG. 17—COMPARISON OF CALCULATED AND MEASURED LOSSES, TEST 10

across the corner of the open delta which amounted to 13,500 volts with 203 kv. at Junction. One-third of this appears across each leg of the low tension. The triple-frequency leg voltage multiplied by the ratio of transformation gives the triple-frequency voltage across each leg of the high tension, and this voltage (75,000 in this case) appears between the neutral and ground. Such voltages may be expected with Y-Y connection without tertiary winding, and it will be noted that they rise to very high values.

COMPARISON OF CALCULATED AND TEST CORONA LOSSES

It is very difficult to get the true loss, either tested or calculated. The test loss must necessarily be taken on the low-tension side and is subject to correction for the transformer core loss and i^2r loss and the transmission line i^2r loss. Phase angle corrections of instrument transformers change the results. On account of the rise in voltage over the line, it is doubtful to what voltage the loss should be referred. On the other hand, in calculating the loss, there are certain assumptions to be made as to the irregularity factor, the spacing of conductors, etc. Corona loss starts first on the middle conductor and this is not taken into account in figuring e_0 with the geometrical mean spacing.

Nevertheless the tests here recorded are believed to be fairly accurate and the results representative of the actual corona loss. Also the calculated losses represent the losses accurately within the limitations of the formulas for a line which fulfills the assumed conditions.

TABLE XXII

COMPARISON OF MEASURED AND CALCULATED LOSSES TEST NO. 10

Reading No.	Kv. H. V. by calc.	Amp. L. V. $i + j\,i_1$	Transformer Exc. Cur. $i_2 - j\,i_3$	H. V. Line Cur. (L. V. Equiv.) $i_4 + j\,i_5$	Amp. H. V. by calc.
44	76.2	7.76 + 205.1j	4.24 − 2.65j	3.52 + 207.75j	11.5
45	96.0	10.07 + 254.0j	5.72 − 5.31j	4.35 + 259.31j	14.4
46	105.0	10.95 + 274.8j	6.27 − 7.54j	4.68 + 282.34j	15.7
47	112.3	13.36 + 292.0j	6.38 − 9.92j	6.98 + 301.92j	16.8
48	121.5	16.11 + 312.7j	6.88 − 14.45j	9.23 + 327.15j	18.2
49	131.0	28.0 + 327.0j	7.65 − 21.79j	20.35 + 348.79j	19.4
50	139.0	39.28 + 337.8j	8.38 − 31.09j	30.90 + 368.89j	20.6
51	148.9	74.8 + 336.0j	10.45 − 54.53j	64.35 + 390.53j	22.0
52	158.0	113.95 + 345.2j	12.6 − 89.15j	101.35 + 434.35j	24.8
53	163.8	140.1 + 328.3j	13.22 − 117.2j	126.88 + 445.5 j	25.7

Reading No.	Total meas. loss	Trans. core loss	L. V. I^2R	H. V. I^2R	Line I^2R	Sum of core & I^2R	Net corona loss	Calc. corona loss
44	56	32	2.18	2.19	6.55	42.92	13	0
45	91	49	3.28	3.42	10.24	65.94	25	0
46	109	59	3.90	4.05	12.11	79.06	30	0
47	142	66.5	4.41	4.47	13.38	88.76	53	12
48	184	78.5	5.06	5.44	16.27	105.27	79	122
49	346	94.0	5.55	6.18	18.50	124.23	222	350
50	514	110.0	5.97	6.94	20.78	143.69	370	644
51	1051	143.0	6.10	7.93	23.73	180.76	870	1118
52	1700	189.9	6.82	10.15	30.39	237.26	1463	1668
53	2165	231.8	6.60	10.89	32.6	281.89	1883	2088

See Fig. 17.

In Fig. 17 is given a comparison between the tested and calculated corona losses for Test No. 10. In these and the following calculations m_0 is assumed as 0.85 and m_v as 0.82. The test readings were corrected for instrument and instrument transformer errors, and from the total losses thus found are substracted the transformer core and i^2r loss and the line i^2r loss (see Table XXII). The high-tension voltage is calculated from the low-tension voltage and the constants of the transformers, and this voltage is considered uniform throughout the line. The corona losses are calculated and plotted against this high tension voltage. The calculated losses are higher than the test losses except at the lower part of the curve. Calculated e_0 is 108.1 while the test e_0 is about 120 kv. Calculated e_v is 148.5 kv.

In Fig. 18 are given comparisons of calculated and test losses for Tests 15 and 18. In this case the test losses given are the total losses, including transformer

losses and line i^2r. The voltage is the low-tension voltage times the ratio, uncorrected for rise through the transformer. The comparison here is useful mainly in showing the shape of the curves. The calculated e_0 for Test 15 is 86.6 kv. based on storm $e_0 = 0.8$ fair weather e_0. This is apparently too low a value. It may be that the rain was not sufficient to give such a lowering of e_0, although reports showed that there

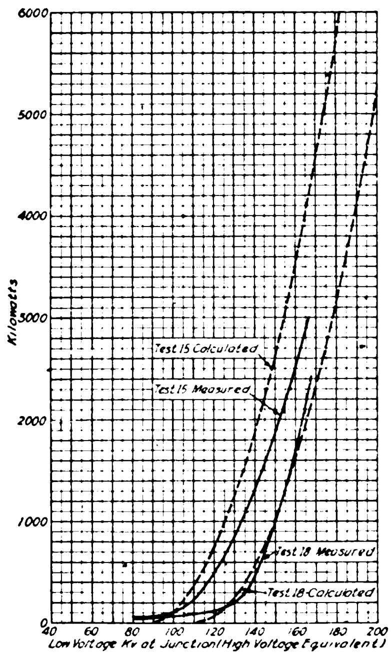

FIG. 18—COMPARISON OF CALCULATED AND MEASURED LOSSES, TESTS 15 AND 18

was a gentle drizzle at the two ends of the line and at Croton, part way along the line. The calculated e_v for Test 15 is 148.8 kv. For Test 18 the calculated e_0 is 110.4 and e_v 151.1 kv.

Fig. 19 gives a comparison of tested and calculated losses for Test 20. The test loss is the total loss less the transformer loss and line i^2r loss, (see Table XXIII). The calculated loss is plotted for the average of the high-tension voltages at Junction and Grand Rapids. Calculated e_0 is 107.5 kv., and e_v 148.6 kv.

In Fig. 20 are plotted the net corona loss (that is total test loss minus transformer loss at both ends of

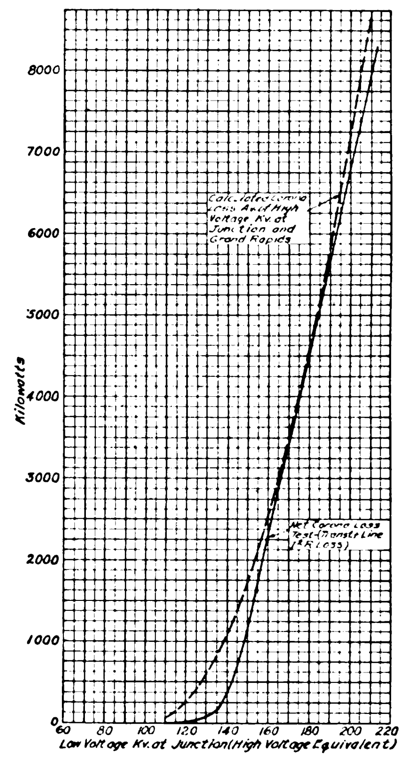

FIG. 19—COMPARISON OF CALCULATED AND MEASURED LOSSES, TEST 20

line and line i^2r loss) and the calculated corona loss for Test 42, (see Table XXIV). The losses are plotted against the average of the high-tension voltages at the two ends of the line as found by test. The calculated e_0 in this case is 108.9 and e_v is 149.3 kv.

The test readings of Tests 20 and 42 are subject

TABLE XXIII
COMPARISON OF MEASURED AND CALCULATED LOSSES
TEST NO. 20

L. V. Kv. Junction (H. V. Equiv.)	L. V. Amp. Junction (H. V. Equiv.)	$i_1 + j\,i_2$	Trans. Exc. Cur. Assumed 90° lag	Line Current $i_3 + j\,i_4$	H. V. line cur. amp.	H. V. Kv. Junction calc.	H. V. Kv. Grand Rapids L. V. × ratio	Avg. H. V. Kv. Jct. & Grand Rapids	Total loss from test	Trans. loss Jct.	Trans. loss G. R.	I^2R line loss	Total trans. + line loss	Net corona loss	Calc. corona loss Avg. H. V. Kv.
100	16.1	0.370 + 16.09j	0.12	0.37 + 16.21j	16.22	102.1	109.5	105.8	60	25	30	13	68	0	0
110	16.5	0.397 + 16.49j	0.15	0.40 + 16.64j	16.65	112.1	120.0	116.1	75	30	35	14	79	0	48
120	17.8	0.490 + 17.79j	0.20	0.49 + 18.28j	18.30	122.2	130.8	126.5	100	34	41	16	91	9	240
130	19.4	0.815 + 19.39j	0.24	0.82 + 20.21j	20.22	132.5	141.2	136.9	160	40	47	20	107	53	576
140	21.6	1.945 + 21.51j	0.25	1.95 + 21.76j	21.82	142.6	152.0	147.3	475	46	53	23	122	353	1058
150	24.5	4.73 + 24.03j	0.26	4.73 + 24.29j	24.85	153.0	162.5	157.8	1250	52	61	30	143	1107	1698
160	27.9	9.21 + 26.32j	0.26	9.21 + 26.58j	28.10	163.2	173.2	168.2	2550	58	70	39	167	2383	2488
170	31.8	12.27 + 29.32j	0.30	12.27 + 29.62j	32.08	173.4	183.9	178.7	3600	66	79	51	196	3404	3412
180	35.8	15.06 + 32.49j	0.40	15.06 + 32.89j	36.15	183.8	194.5	189.2	4700	75	90	64	229	4471	4495
190	39.3	17.65 + 35.1 j	0.60	17.65 + 35.70j	39.80	194.1	205.0	199.6	5850	86	104	78	268	5582	5713
200	42.9	20.39 + 37.72j	0.80	20.39 + 38.52j	43.60	204.2	215.9	210.1	7100	98	123	93	314	6786	7100
210	46.4	23.1 + 40.22j	1.25	23.10 + 41.47j	47.50	214.8	226.5	220.7	8325	113	150	111	374	7951	8600
220	49.8	25.9 + 42.55j	1.75	25.9 + 44.3 j	51.30	225.0	237.1	231.1	10000	133	184	130	447	9553	10300

See Fig. 19

TABLE XXIV
COMPARISON OF MEASURED AND CALCULATED LOSSES
TEST NO. 42

L. V. Kv. Junction (H. V. Equiv.)	L. V. Amp. Junction (H. V. Equiv.)	$i_1 + j\, i_2$	Trans. Exc. Cur. Assumed 90° lag	Line Current $i_3 + j\, i_4$	H. V. line cur. amp.	H. V. Kv. Junction calc.	H. V. Kv. Grand Rapids L. V. ratio	Avg. H. V. Kv. Jct. & Grand Rapids	Total loss from test	Trans. loss Jct.	Trans. loss G. R.	I^2R line loss	Total trans. + line loss	Net corona loss	Calc. corona loss Avg. H. V. Kv.
100	15.3	0.268 + 15.29*j*	0.12	0.27 + 15.41*j*	15.42	102.0	97.8	99.9	60	26	24	12	62	0	0
110	16.4	0.377 + 16.39*j*	0.15	0.38 + 16.54*j*	16.54	112.0	109.8	110.9	75	30	30	13	73	2	3
120	17.6	0.554 + 17.59*j*	0.20	0.55 + 17.79*j*	17.80	122.1	121.1	121.6	110	35	36	16	87	23	108
130	19.0	0.874 + 18.98*j*	0.24	0.87 + 19.22*j*	19.24	132.5	132.5	132.5	190	40	42	18	100	90	372
140	20.8	2.81 + 20.6 *j*	0.25	2.81 + 20.85*j*	21.02	142.5	143.9	143.2	675	46	48	22	116	559	788
150	23.5	5.88 + 22.8 *j*	0.26	5.88 + 23.06*j*	23.80	152.7	155.1	153.9	1525	52	56	28	136	1389	1344
160	27.7	9.00 + 26.18*j*	0.26	9.00 + 26.44*j*	27.95	163.2	166.2	164.7	2500	59	64	38	161	2339	2079
170	31.7	11.99 + 29.32*j*	0.30	11.99 + 29.62*j*	32.00	173.5	177.3	175.4	3560	67	73	50	190	3370	2952
180	35.4	14.86 + 32.12*j*	0.40	14.86 + 32.52*j*	35.76	183.8	188.1	186.0	4680	75	83	63	221	4459	3970
190	38.9	17.60 + 34.68*j*	0.60	17.60 + 35.28*j*	39.40	194.1	199.0	196.6	5900	85	97	76	258	5642	5120
200	42.3	20.12 + 37.20*j*	0.80	20.12 + 38.00*j*	43.00	204.1	209.5	206.8	7000	97	111	91	299	6701	6160
210	45.7	22.50 + 39.80*j*	1.25	22.50 + 41.05*j*	46.80	214.8	220.0	217.4	8130	112	138	108	353	7777	7840
220	48.9	24.45 + 42.38*j*	1.75	24.45 + 44.13*j*	50.50	225.0	229.8	227.4	9250	133	160	125	418	8832	9380

See Fig. 20

to correction for instrument and instrument transformer errors, which would probably increase the values of kilowatts at the low points.

It is evident from a comparison of the test and calculated curves shown on Fig. 17 to 20 inclusive that

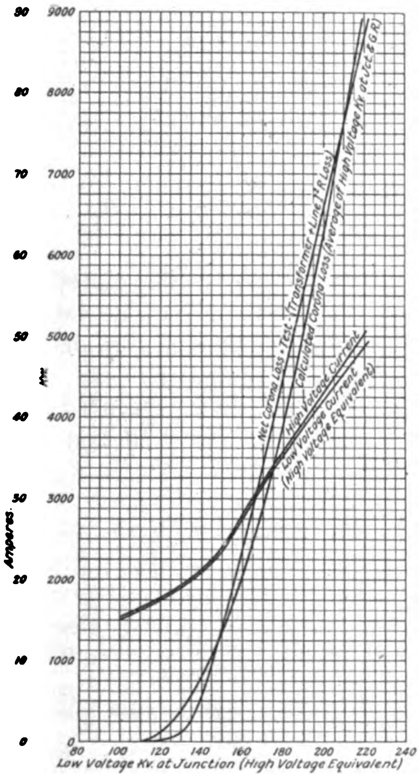

FIG. 20—COMPARISON OF CALCUALTED AND MEASURED LOSSES, TEST 42

while these curves are in general very much alike in shape and magnitude, still there are some marked discrepancies, and at the lower part of the curve in particular there are noticeable deviations. The test curves in all cases give a lower loss and have a more abrupt bend than the calculated curves. Peek explains this by saying that below e_v the quadratic law does not hold, that the loss here is due to irregularities and that the probability law governs. The probability law is stated:

$$P_1 = q^{-h\,(e_v - e)^2}$$

in which q is a coefficient depending on the number of spots and h is a coefficient depending on the size of the spots. This loss, therefore, depends on two coefficients whose value it is difficult to approximate.

Peek further states that it is of practical importance only to know the limits of the loss on this part of the curve and that e_0 should generally be the limit of the voltage on practical lines, as otherwise storm losses become excessive. This is very well taken and we have no doubt that Peek has stated the case correctly. The desirability of operating below e_0 is more evident than ever in view of the ground current described in this paper.

Nevertheless a large number of systems are operating between e_0 and e_v and in figuring on new systems or extensions to old systems, it is frequently an economical problem whether to go to a larger size conductor or to stand a limited amount of corona loss. In these cases it is desirable to be able to calculate approximately the losses between e_0 and e_v, and to know whether the actual losses will be higher or lower than the calculated losses.

It is doubtful whether the present data are sufficient or of enough accuracy to use in checking the corona law, but it would seem desirable that the law be checked by actual line tests to determine whether or not there is any regularity or uniformity below e_v or whether the deduction of any general law is hopeless, as intimated by Peek.

CHANGE IN CAPACITANCE

Some discrepancies were noted in these tests between the calculated charging current and the tested charging current of the line, between the calculated

voltage increase along the line and the measured voltage rise, also between the calculated ground current and the measured ground current. These quantities may be brought closer together by assuming that the corona which breaks down the air surrounding the

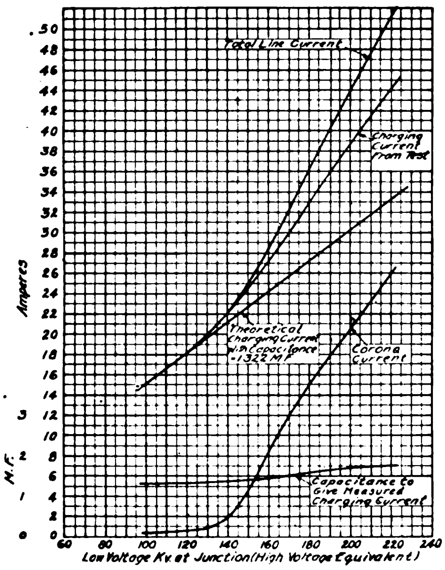

FIG. 21—COMPARISON OF CALCULATED AND MEASURED CHARGING CURRENT, TEST 20

conductor and makes it conducting has the effect of increasing the diameter of the conductor, thereby increasing the capacitance and decreasing the inductance from the calculated values. Also the harmonics placed in the voltage by the corona would naturally increase the charging current and the rise in voltage along the line.

TABLE XXV

COMPARISON OF MEASURED AND CALCULATED CHARGING CURRENT

TEST NO. 20

L. V. Kv. Junction (H. V. Equiv.)	Avg. H. V. Kv. Junct. & Gr. Rapids	Calc. chg. current $C = 1.322$ microfarads	Test chg. current	Capacity to give test chg. current microfarads
100	105.8	15.2	16.2	1.406
110	116.1	16.7	16.6	1.313
120	126.5	18.2	18.3	1.33
130	136.9	19.7	20.2	1.356
140	147.3	21.2	21.8	1.36
150	157.8	22.7	24.3	1.415
160	168.2	24.2	26.6	1.452
170	178.7	25.7	29.6	1.522
180	189.2	27.2	32.9	1.598
190	199.6	28.7	35.7	1.642
200	210.1	30.4	38.5	1.685
210	220.7	31.7	41.5	1.728
220	231.1	33.3	44.3	1.76

See Fig. 21.

In Fig. 21 (see table XXV) the total high-tension current of Test No. 20 is plotted, also the power and reactive components, the former being due to the corona loss and the latter being the charging current. The theoretical charging current with constant capacitance of 1.322 microfarads to neutral is also plotted. It will be seen that there is a constantly increasing deviation between the calculated and tested charging currents. The values of capacitance which would give the tested charging current are plotted and it will be noted that they begin at 1.322 microfarads and increase with increasing voltage.

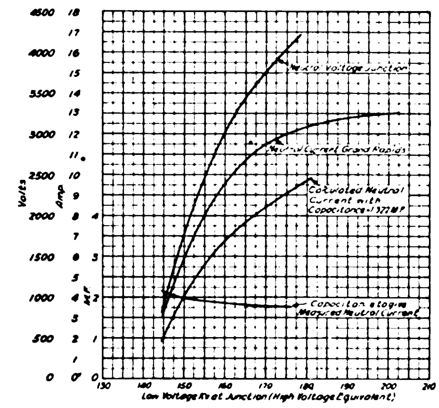

FIG. 22—COMPARISON OF CALCULATED AND MEASURED CURRENT IN GROUNDED NEUTRAL, TEST 44

On Fig. 22 are plotted the neutral ground current measured at Grand Rapids in Test 44, the neutral voltage at Junction and the calculated neutral ground current found from the neutral voltage and the theoretical capacitance of 1.322 microfarads from conductor to neutral, (see Table XXVI). The test values are greater than the calculated and tend to become increasingly greater at the higher voltages. There are also plotted the values of capacitance which would give the measured charging current. These are greater than 1.322 microfarads but appear to decrease with increasing voltage. This is not consistent with the preceding paragraph, in which the capacitance is found to increase with increasing voltage. If we assume that not all the neutral current is capacitance current, but part of it is true power, or corona current, then we can arrive at a reasonable capacitance curve. We, however, introduce a new element into corona loss, namely a triple-frequency component.

TABLE XXVI

COMPARISON OF MEASURED AND CALCULATED NEUTRAL CURRENT

TEST NO. 44

L. V. Kv. Junction (H. V. Equiv.)	Volts Neut. to Ground	Calc. neut. current $C = 1.322$ microfarads	Test neut. current chg.	Capacity to give test neut. current microfarads
145	900	2.02	3.25	2.128
150	1800	4.04	6.0	1.963
155	2475	5.55	8.0	1.903
160	3000	6.73	9.6	1.884
165	3425	7.68	10.75	1.849
170	3750	8.42	11.5	1.806
175	4030	9.04	12.0	1.754

See Fig. 22.

The actual rise in voltage over the line is apparently greater than the calculated rise, for example the tested rise in Test No. 42 at 180 kv.(equivalent high voltage) is 4300 volts or 2.34 per cent, while the calculated rise is only 600 volts or 0.33 per cent.

The above calculations are based on a capacitance of 1.322×10^{-6} farad and a reactance of 41.5 ohms for the 101.5-mile line, which are the calculated values for the particular size and spacing of conductor. Now if the radius of the conductor is increased to give increased capacitance as shown on Figs. 21 and 22, most of the calculated results show a much closer agreement to the tests. From this it appears that the radius of the conductor increases with the corona, perhaps being a function of the excess of the applied voltage over the critical corona voltage. The rise in voltage along the line is only partly accounted for in this manner, and harmonics may play a controlling part here.

Conclusions

Corona losses at approximately 210 kv. at the generating end and 225 kv. at the receiving end of a 100-mile line of 110,000-cir. mil conductor have been recorded.

The losses in general follow Peek's law, with some deviation especially at the lower voltages, where the tested loss is as a rule less than the calculated.

A current in the grounded neutral was encountered which at the higher voltages was about 40 per cent of the line current. This current begins at about the normal line voltage. It is apparently due to the corona, which causes a pulsation in the voltage wave and a triple-frequency current to flow through the capacitance to ground and back through the grounded neutral.

The line charging current, the current in grounded neutral and the rise in voltage along the line are all greater than calculated from the geometrical capacitance. This may be accounted for by an increased capacitance due to increased diameter of conductor caused by corona. Harmonics introduced into the voltage wave by the corona may contribute to the effect noticed.

The tests indicate a difference in corona loss with the neutral grounded and isolated, probably due to the flow of triple-frequency current in one case, and the distortion of voltage by triple-frequency component in the other.

The danger of overvoltage across legs and between neutral and ground with Y-Y connection is shown by Test 24.

The tests clearly indicate the desirability of operating a transmission line below the corona voltage, thus avoiding corona loss and its accompanying effects.

A NEW EXCHANGE BETWEEN FRENCH AND AMERICAN UNIVERSITIES

There has been for some time a regular annual exchange of professors between individual universities in France and America in regular academic fields, but there has never been, as yet, any such exchange in engineering or applied science. These subjects are taught in France under special faculties, not included in existing exchanges with America. Furthermore, the French methods of teaching these subjects are unlike our American methods, for various reasons, based on the history, traditions and sociology of the two countries. The great war showed the importance of engineering in production and distribution, and the many ties of friendship which bind us to France depend, in various ways, upon applied science. It should therefore, be to the mutual advantage of France and America to become better acquainted with each other's ideals and viewpoints, in the study and in the teaching of these great groups of subjects.

With these purposes in mind, the late Dr. R. C. MacLaurin, in 1919, as President of the Massachusetts Institute of Technology, consulted the presidents of six universities on or near the Atlantic seaboard, as to whether they deemed it desirable to cooperate in such a joint exchange of professors with France, on a plan definitely outlined. Their replies being very favorable to the project, a committee was appointed, with one member from each of the seven institutions, to report on the plan, and on methods of carrying it into effect. The committee met in December 1919, and ratified the cooperative plan with some few modifications. The present president of the committee is Director Russell H. Chittenden of Yale, and its secretary Dean J. B. Whitehead of Johns Hopkins.

Since the Institute of International Education in New York concerns itself with the interchange of college students and teachers from all parts of the world, the committee requested the Institute's director, Dr. Stephen P. Duggan, to undertake the negotiations between the committee and the French University Administration. The French have selected, for their first representative, Professor J. Cavalier, rector of the University of Toulouse, and a well-known authority on metallurgical chemistry, to come to America this fall, and to divide his time during the ensuing academic year among the seven cooperating institutions, namely, Columbia, Cornell, Harvard, Johns Hopkins, Massachusetts Institute of Technology, Pennsylvania and Yale.

The American universities have selected as their outgoing representative for the same first year (1921-22), Dr. A. E. Kennelly, professor of electrical engineering at Harvard University and the Massachusetts Institute of Technology.

Long-Distance Transmission of Electric Energy

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The paper discusses long-distance transmission of electric energy dealing with (1) the economic conditions which justify it, (2) the plant involved, and (3) the service that may be expected.

The economic conditions which justify long-distance transmission of electric energy are a cheap source of power with an insufficient local demand to absorb it, and a distant market to which the energy can be delivered cheaper than energy con be supplied at that point from any other source.

In dealing with the plant required for long-distance transmission some of the considerations that affect the design are discussed. A graphic method of determining line performance is illustrated by an example and some essential data on other lines are given. Among the important physical considerations entering into transmission line design, right of way, spacing of towers, line insulators, high-tension switches and lightning arresters are discussed.

Service is considered from the viewpoints of, what people demand, what perfect service will cost, and the service that may be expected from a large interconnected system consisting of steam plants at the mines, hydro plants wherever available and local steam plants.

IT IS PROPOSED in this paper to discuss long-distance transmission of electric energy from three standpoints. First, from the economic point of view, by consideration of the conditions which justify long-distance transmission. Second, from the physical viewpoint, by dealing with the design, construction, and operation of long-distance lines. Third, from the point of view of service, by consideration of the factors, contributing to continuity of service and its value to the people served. This discussion is to some extent based on studies which have recently been made in the development of a superpower system, for the industrial district along the Atlantic Seaboard.

THE ECONOMIC JUSTIFICATION FOR LONG-DISTANCE TRANSMISSION

The laws governing the distribution of electric energy under ordinary conditions, losses involved and the various items entering into distribution costs, are fairly well-known. However, when large amounts of electric energy are to be transmitted over long distances the problem is greatly complicated by factors which do not appear, or are negligible in the ordinary distribution of energy. In every power transmission problem the question to be answered is: Can energy be generated and transmitted to the point where it is needed more cheaply than it can be generated at the point of demand?

The two available sources of power at the present time are expansive force of steam and the energy of water acting from force of gravity. In addition to these we have various forms of chemical energy, energy from internal combustion engines, the mercury vapor engine, energy from the winds and tides and heat energy from the sun, but the application of these as prime movers to the generation of millions of kw-hr. for general distribution appears to be remote.

The point at which energy can be developed by water power is located for us by nature and we must make what we can of it. A power plant located at a waterfall is rarely in an industrial community or where an industrial community may be developed. There are exceptions to this as at Niagara Falls, but in general waterfalls are in out of the way places and their use for power development must either await a local demand, after factories or electrochemical works are built, or the energy must be transmitted to already developed communities where there is demand for it. The problem is whether it will pay to develop it at all, and if this is answered in affirmative whether it will pay better to use the energy nearby or to transmit it to a distant market.

Electric energy by whatever source of power it may be generated should be used in such manner as to supply the economic needs of the country at maximum efficiency. This in general means that hydroelectric energy generated at waterfalls away from centers of industry and steam-electric energy generated at the coal mines must be transmitted to distant centers of demand in order to find a market; but if a demand should exist near the place where the power is generated then that demand must be supplied first, and only the residue, if any, transmitted to the more distant point. This statement should be qualified by the proviso that the local demand for energy be such that the economic needs of the country be supplied by that means more cheaply than in any other way. For example, energy generated by water power at Niagara Falls should be used at that point for the manufacture of chemicals needed by all the people of the country and which can be manufactured and marketed from there more cheaply than anywhere else, rather than sent to New York with the attendant losses and cost of transmission. Niagara Falls energy should not be used locally for heating dwelling houses and factories, even if the producers could furnish it for this purpose, at a profit to themselves, as houses can be heated more economically in some other way. If such use were the only local means of absorbing Niagara energy, then such energy should be sent to a more distant market where it would serve a better purpose. Furthermore, Niagara energy should not be sent to more distant points so long as

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there is a demand for it in Buffalo, or nearby cities. If, however, hydroelectric energy can be developed at Niagara Falls faster than it can be absorbed in the surrounding territory, it would be in order to build transmission lines to convey the excess energy even as far as New York provided it can be sold at a price which would permit the amortization of the transmission plant while the local demand is being built up. Thus if governmental permission could be obtained to divert water from the Niagara River for generation of 600,000 kw. it is quite within economic possibility that a block of 300,000 kw. could be transmitted to New York and sold at a price which would net a profit to the promoters and provide an adequate sinking fund to retire the investment in transmission equipment. The reason such expenditure can be justified is that energy in bulk is worth about three times as much in New York as it is worth in Niagara Falls.

There are many places where electric energy may be generated from water power where there is locally no present or prospective demand for it. Such locations in the eastern states where large amounts of undeveloped energy may be obtained are the St. Lawrence River, the rivers of the Adirondack Mountains, and the rivers of Maine. The question here is: Can these developments be made and the energy transmitted to any existing, or prospective markets, cheaper than a like amount of energy can be generated at the point where the demand exists, or developed and transmitted to that point from any other source? The competing source of energy will probably be steam-electric energy generated locally or at the mines.

In the case of long-distance transmission of energy from steam plants the same law holds good, that such energy should be used as near the point where it is generated as possible, provided the needs of the country are thereby supplied more cheaply than in any other way. If, for instance, there should be found an economic demand in the anthracite region of Pennsylvania for all the energy that can be generated in that region, due to limitation in supply of condensing water or steam sizes of coal, or to any other cause, then such energy should all be used in the anthracite region. In any case only the residue, after supplying the local needs, should be transmitted to distant centers of demand. The anthracite mines are very deep and require much energy for pumping ventilation and for haulage. In this region it requires 20 kw-hr. of energy to mine and place on the cars one ton of coal. When all the mines are electrified as they probably will be within the next few years, the 80,000,000 tons of coal mined per annum will require 1,600,000,000 kw-hr. of energy at a demand rate of about 400,000 kw. The railroads in the anthracite region will doubtless soon have to be electrified on account of the heavy tonnage and the steep grades. This territory is also developing a large miscellaneous industrial load. It is estimated that approximately 800,000 kw. will be required to supply the total demand for electric energy in this region within the next ten years. All this demand will have to be satisfied, before energy is sent from this region to distant markets.

There are limitations in generating power in the anthracite region due to the amount of condensing water and steam sizes of coal which are available. If, however, highly efficient generating plants are built to supply the 800,000 kw. needed for the local demand, considerable off peak power will be available for transmission to such load centers as New York and Philadelphia. There is also considerable diversity of load between these centers as the peak of the load in the Metropolitan District does not come on until a large part of the load in the anthracite region has gone off.

In the bituminous fields of the Appalachian region the conditions are very different from the conditions in the anthracite field. Very little shaft mining is done and consequently very little energy is needed for pumping water or hoisting. This condition will exist for some years until deep level mining becomes necessary. Eighty per cent of the bituminous mines are already electrified—the principal use of energy being for mine haulage. Therefore, almost all the energy which can be generated at the bituminous mines is available for distant markets.

Unfortunately there are few locations near the mines within reasonable transmission distances of load centers along the Atlantic seaboard where steam plants can be located convenient to coal supply and where there is ample condensing water. Investigation shows that there is no location within 300 miles of New York City where both coal and water can be found for a 100,000-kw. high-efficiency steam plant without the necessity of transporting coal from 10 to 50 miles by railroad. Therefore, quite an appreciable freight charge is involved even for such plants.

The cost of gathering coal from the mines and delivering it to the power plant which must be located where condensing water is available, has a very important bearing on the general problem of transmission of electrical energy from the coal mines. In order to justify the transmission it is necessary to show that the value of the energy lost plus the fixed charges on the cost of the transmission plant is less than the net cost of freight on coal required to generate the same amount of energy at the point of use.

In view of what has been said the economic justification for long-distance transmission of energy may be stated as follows: In the case of all energy generated, either steam-electric or hydroelectric, after the local demand has been satisfied, the residue may be transmitted to distant centers of demand when it can be delivered more cheaply than the energy can be supplied at that point from any other source.

Long-Distance Transmission Lines

It is not the purpose of this paper to show how to design high-tension transmission lines, nor how to calculate the performance of these lines, but to point out some of the considerations that must be taken into account and to give some typical examples of design and line performance that have been worked out.

A transmission line should be capable of transmitting the amount of energy for which it is designed at minimum cost. Kelvin's law may be used in the design of high-tension lines by including in the investment the cost of other apparatus which varies for the different sizes of conductors compared, as for example, towers, insulators, transformers, synchronous condensers, switch equipment, etc., the interest and depreciation on which shall equal the value of the energy lost. The law, however, must be applied with the reservation that corona must not be the limiting factor. The design of long-distance lines differs from the design of ordinary circuits for carrying electric energy in that certain factors must be taken into account that may usually be neglected. Corona, reactance and capacitance are each factors that have to be carefully reckoned with. Each of these characteristics present definite limitations which are susceptible of accurate determination in advance. These same limiting characteristics are useful in the operation of the line and may be regarded as making long-distance transmission of electricity possible.

Corona becomes a serious limitation to long-distance transmission at high voltage. There is a critical disruptive voltage for each size of cable, depending on the spacing and arrangement of conductors, the elevation above sea level and the meteorological condition of the atmosphere. Rain, fog, and particularly falling snow increase the tendency for energy to discharge from the conductors and lowers the critical voltage.

Thus for a particular voltage, elevation and climatic condition, there is a definite lower limit to the size of conductor that can be used irrespective of whether this is the most economical section so far as cost balanced against losses is concerned. It may easily happen in a particular instance that diameter in transmission conductor is more important than conductivity and this may determine the material of which the cable is composed or the manner in which it is made. Increase in diameter may be obtained by using aluminum or copper cable with steel core. Corona, however, has at least one redeeming quality in that it doubtless assists materially in dissipating induced high-frequency charges on the line that otherwise would be destructive to insulation of line, transformers and switches.

Reactance limits the amount of energy that can be transmitted over a given line. It varies with the size, arrangement and spacing of the conductors and the reactance volts vary with the current to be transmitted. With a particular line and a definite amount of energy to be transmitted the reactance voltage drop to be dealt with is decreased by increasing the vo tage. Where reactance is the factor limiting the amount of energy that can be transmitted over a given line the only way to increase the amount of energy that can be transmitted is to increase the voltage. This in turn may be limited by corona unless the diameter of the cable is increased. Increase in size and consequent cost of conductors for a particular transmission has a definite limit depending on the cost of producing energy in some other way at the point of destination. Reactance is useful, in that it limits the current that can flow in case of short circuit. It thus prevents destruction of the windings of transformers from excessive mechanical strains and makes it possible for switches to open the circuit during short circuits by limiting the flow of current to an amount that can be successfully broken.

It may be mentioned here that by an arrangement of divided conductors, two cables being suspended from one insulator a few inches apart and used as a single conductor—the reactance of the line may be greatly reduced and its capacity proportionally increased. This will enable the line to transmit a much greater amount of energy without increasing the synchronous condenser capacity necessary to regulate it, or conversely if the amount of energy is not increased less synchronous condenser capacity will be required. This advantage is obtained without increase in weight of copper and change in resistance of conductors. The following illustrates the effect of thus dividing the conductors:

	Single Conductors	Divided Conductors
Length of line	350 miles	350 miles
Size of conductor.........	(1)—605,000 cir. mils	(2)—302,500 cir. mils
Energy transmitted per circuit..................	150,000 kw.	150,000 kw.
Voltage of transmission....	220 kv.	220 kv.
Losses..................	14,900 kw.	18,180 kw.
Synchronous condenser capacity required at full load.	76,000 kv-a.	40,350 kv-a.

Capacitance determines the charging current of a line, and depends on spacing, diameter and arrangement of the conductors, frequency and length of the circuit. If full voltage is impressed on a transmission line at the generating end and the receiving end of the line is left open the voltage of the receiving end may rise to such a value as to cause serious damage. At the same time the charging current flowing into the line which must be supplied by the generators may be equal to or even greater than the energy current on the line when fully loaded. This may be much in excess of the capacity of one of the largest generators in the generating station. In case of the 350-mile 220-kv. line just mentioned with single conductors the charging current which must be furnished at the generating station with 220 kv. impressed on the line at 60 cycles is nearly 100,000 kv-a. for each three-phase circuit (200,000 for the two circuits in parallel). This is about equal to the current carrying capacity of four 50,000-kw.

(59,000-kv-a. at 85 per cent power factor) generators operating in parallel. In other words, it will require generator capacity necessary to provide 200,000 kv-a. leading current to energize such a two-circuit line designed to transmit 150,000 kw. The charging current being leading in the armature of the generator tends to increase its excitation thus making it self-exciting, possibly to such an extent that it becomes beyond control of the separate field excitation usually provided. In the case cited above, if the frequency were 25 cycles, the charging kv-a. would be about 40,000.

Synchronous condenser or synchronous reactor capacity may be so adjusted to a transmission line as to neutralize lagging or leading current at any point in the line. Capacitance in a line serves much the same purpose as synchronous condenser capacity, the difference being that the former is distributed along the line and cannot be controlled, while condensers are generally located at the receiving end only and can be adjusted to compensate for change in power factor and load. In gradually loading up a line there is a point at which the charging current resulting from capacitance just balances the reactance thus giving unity power factor at the generating end of the line. On a long transmission line it may be found advisable at normal loading to operate with a leading power factor at the generating end of the line which results in unity power factor near the middle of the line and a lagging power factor at the receiving end.

Many factors enter into the choice of voltage for a transmission line. Other conditions being equal, that voltage should be chosen which will permit the energy to be transmitted at minimum cost. The writer knows of one instance where 100,000 kw. was transmitted 2½ miles at 12,000 volts as the price of copper was such that the interest on the investment in copper plus the value of the energy lost in the 12,000-volt circuits was less than the interest on the cost of step-up and step-down transformers, and the other items of cost that the higher voltage would have involved. The economic voltage is dependent upon the amount of energy involved. In the case of very long lines and large amounts of energy the economic voltage is the highest that the state of the art will permit. This at the present time is about 220,000 volts. On shorter lines it may be desirable to adopt a voltage that corresponds to that of other lines in the vicinity in order that the circuit may run in parallel without the introduction of transformers. Determination of the proper voltage for a project requires careful analysis of all the factors bearing on the problem after full knowledge of the value of these factors has been ascertained.

Frequency will generally be determined by the prevailing frequency of the district to be supplied. Up to 350 miles it is practicable to design operative transmission lines for either 60 or 25 cycles, the prevailing frequencies in this country. Beyond this distance it may be found advisable to use the lower frequency in order to keep the reactance and capacitance susceptance within practical limits. There is very good reason to believe that 60 cycles will eventually prevail in this country and all new projects except those involving very long transmission lines should be at this frequency. Even in those communities where 25 cycles now prevail it is usually practicable to take on new business at the higher frequency so that eventually the lower frequency may be retired. In the beginning there was very good reason for the adoption of 25 cycles on account of it being impracticable to build 60-cycle synchronous converters for changing to direct current. Sixty-cycle synchronous converters have now been developed which answer all requirements, and the reason for the lower frequency more expensive apparatus no longer exists.

It is particularly unfortunate that the two prevailing frequencies in this country are such that frequency-changers are necessarily very expensive. There is only one speed, namely 300 rev. per min., which results in a ratio of 25 to 60 cycles. Such machines must have 10 poles for the 25-cycle end and 24 poles for the 60-cycle end, thus necessitating a very expensive machine even for small installations. If 30 cycles had been chosen instead of 25 the matter of changing frequency would have been greatly simplified as the lower frequency machine would then have a pole ratio to the higher of 1 to 2, and in general could be built at much lower cost. This would have been of considerable advantage in the transition of 25-cycle systems in this country to a 60-cycle standard. Or if 50 cycles had been chosen as is generally the case in foreign countries a ratio of 1 to 2 would have also resulted.

The performance of a transmission line may be completely determined graphically with the degree of accuracy necessary for preliminary studies by the use of vector diagrams indicating currents and voltages at the two ends of the circuit and applying the auxiliary constants of the circuit which account for the distribution effect. These constants may be read direct from the Wilkinson Charts. The following illustrations of this graphic method are given as applied to a 225-mile 220-kv., 60 cycle transmission, designed to transmit 300,000 kw. and supply an industrial distributing system at 85 per cent power factor. The transmission will consist of two tower lines, each supporting two circuits; additional line characteristics and load data are given on the diagrams which apply to one 605,000-cir. mil aluminum steel reinforced three-conductor circuit. Under normal conditions each circuit will transmit 75,000 kw. and under emergency conditions will transmit 150,000 kw. The voltage will be held at the high-voltage side of the raising transformers and at the low-voltage side of the lowering transformers. This somewhat simplifies the calculations as it eliminates the impedance of the raising transformers from consideration. In each of these solutions the impedance of the lowering transformers is added to the line im-

pedance and regarded as if it were distributed line impedance. The percentage of error due to this assumption is shown in the lower right-hand corner of each diagram. For an exact determination of the performance of a very long line the complete method of solution would be demanded. In this complete method the localized impedance of the raising and lowering transformers is not considered as distributed line impedance but treated as localized impedance. The illustrations show, in addition to a complete graphical method of solution, the mathematical solution which exactly parallels it. The quantities given on the illustration have been carried out to an extreme degree of refinement so that the error in results as determined by this simplified approximate method compared with the more complicated complete method (not shown here) could be accurately obtained. It may be noted that the approximate solution shown by illustration takes into account the effect of the condenser and lowering transformer losses flowing over the circuit and the effect of the magnetizing current of the lowering transformers in reducing the effective capacity of condenser capacity under load.

Fig. 1 shows the conditions existing at no-load with normal load connections and with line and lowering transformers energized. With 220 kv. at low-voltage side of lowering transformers, synchronous reactor capacity of about 30,000 kv-a. will be required to hold the voltage at sending end at 230 kv. The illustration indicates that this capacity of synchronous reactor will hold the sending end voltage at about 227 kv. but the table of percentage error for this method indicates that the voltage at sending end as determined by this method is about 2.13 per cent low. The complete method would give the sending voltage as 230 under this condition. To maintain

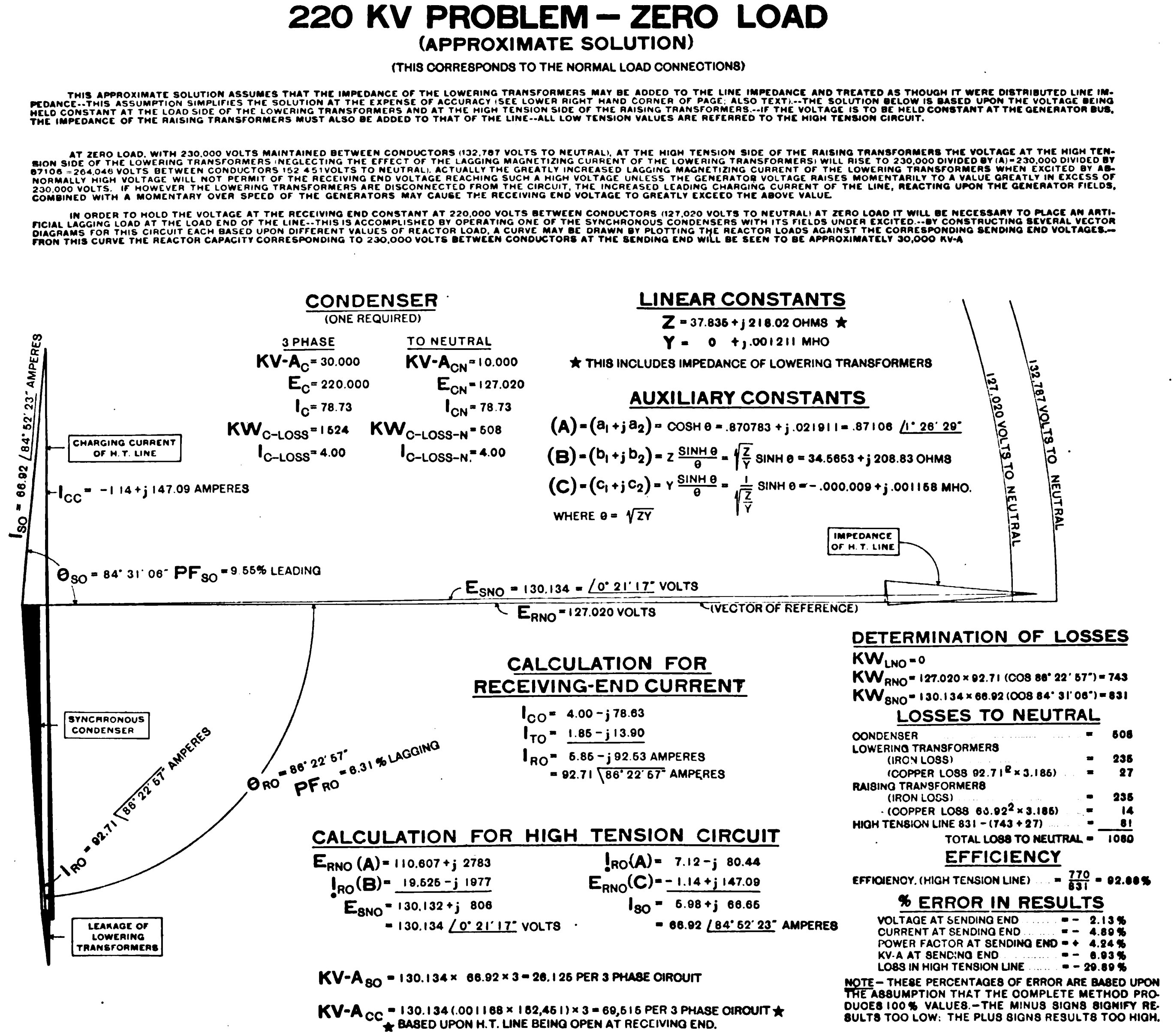

FIG. 1

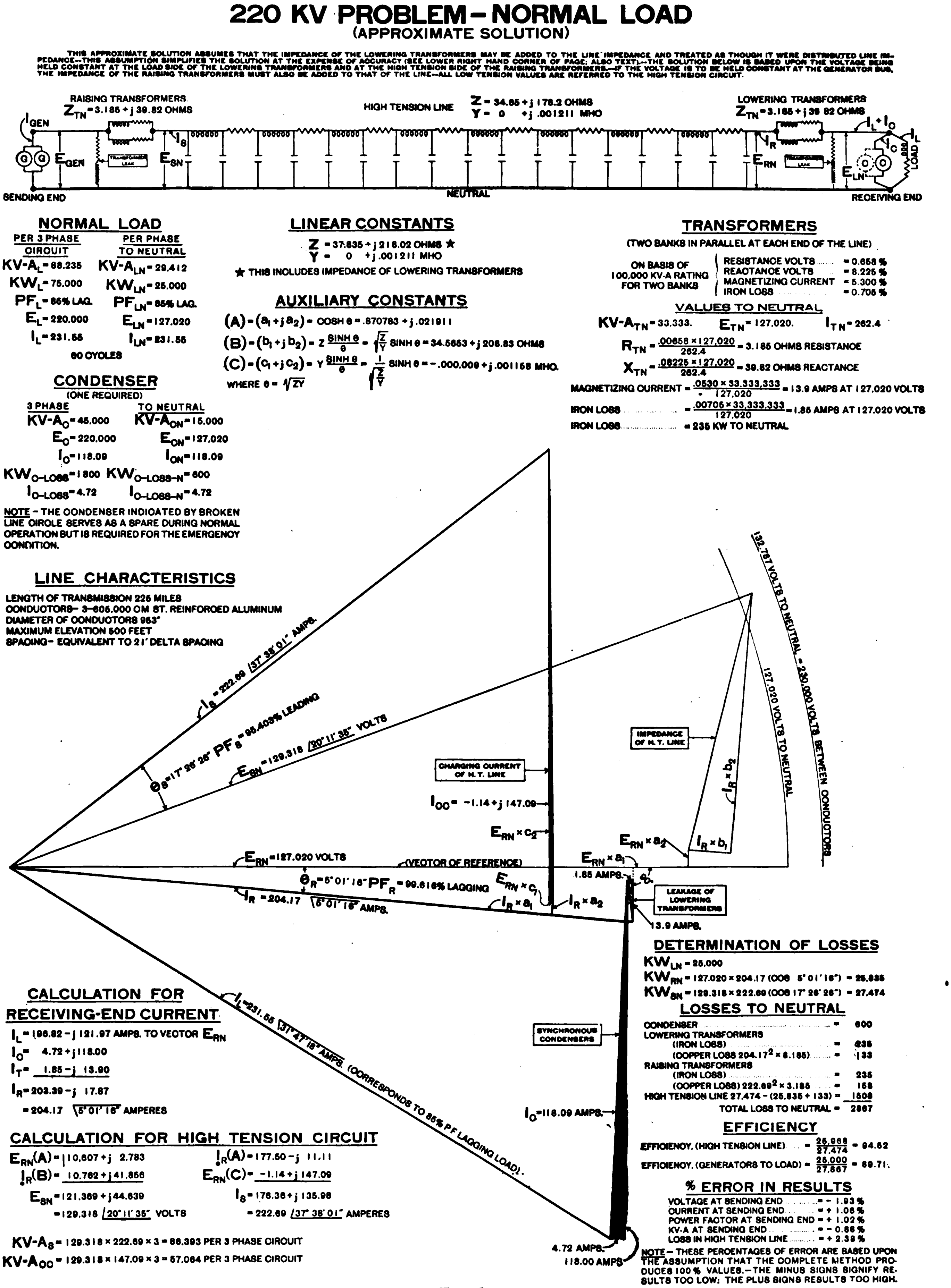
220 KV PROBLEM—NORMAL LOAD
(APPROXIMATE SOLUTION)
THIS APPROXIMATE SOLUTION ASSUMES THAT THE IMPEDANCE OF THE LOWERING TRANSFORMERS MAY BE ADDED TO THE LINE IMPEDANCE AND TREATED AS THOUGH IT WERE DISTRIBUTED LINE IMPEDANCE—THIS ASSUMPTION SIMPLIFIES THE SOLUTION AT THE EXPENSE OF ACCURACY (SEE LOWER RIGHT HAND CORNER OF PAGE; ALSO TEXT)—THE SOLUTION BELOW IS BASED UPON THE VOLTAGE BEING HELD CONSTANT AT THE LOAD SIDE OF THE LOWERING TRANSFORMERS AND AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS.—IF THE VOLTAGE IS TO BE HELD CONSTANT AT THE GENERATOR BUS, THE IMPEDANCE OF THE RAISING TRANSFORMERS MUST ALSO BE ADDED TO THAT OF THE LINE—ALL LOW TENSION VALUES ARE REFERRED TO THE HIGH TENSION CIRCUIT.
RAISING TRANSFORMERS. Z_{TN} = 3.185 + j 39.82 OHMS
HIGH TENSION LINE Z = 34.65 + j 178.2 OHMS Y = 0 + j .001211 MHO
LOWERING TRANSFORMERS Z_{TN} = 3.185 + j 39.82 OHMS
I_{GEN} E_{GEN} E_{SN} I_S I_R E_{RN} $I_L + I_O$ I_L I_C E_{LN} LOAD
SENDING END NEUTRAL RECEIVING END
NORMAL LOAD
PER 3 PHASE CIRCUIT: KV-A_L = 88.235; KW_L = 75.000; PF_L = 85% LAG.; E_L = 220.000; I_L = 231.55
PER PHASE TO NEUTRAL: KV-A_{LN} = 29.412; KW_{LN} = 25.000; PF_{LN} = 85% LAG.; E_{LN} = 127.020; I_{LN} = 231.55
60 CYCLES
CONDENSER (ONE REQUIRED)
3 PHASE: KV-A_O = 45.000; E_O = 220.000; I_O = 118.09; KW_{O-LOSS} = 1800; I_{O-LOSS} = 4.72
TO NEUTRAL: KV-A_{ON} = 15.000; E_{ON} = 127.020; I_{ON} = 118.09; $KW_{O-LOSS-N}$ = 600; $I_{O-LOSS-N}$ = 4.72
NOTE—THE CONDENSER INDICATED BY BROKEN LINE CIRCLE SERVES AS A SPARE DURING NORMAL OPERATION BUT IS REQUIRED FOR THE EMERGENCY CONDITION.
LINE CHARACTERISTICS
LENGTH OF TRANSMISSION 225 MILES
CONDUCTORS—3-605,000 CM ST. REINFORCED ALUMINUM
DIAMETER OF CONDUCTORS .953"
MAXIMUM ELEVATION 500 FEET
SPACING—EQUIVALENT TO 21' DELTA SPACING
LINEAR CONSTANTS
Z = 37.835 + j 218.02 OHMS ★
Y = 0 + j .001211 MHO
★ THIS INCLUDES IMPEDANCE OF LOWERING TRANSFORMERS
AUXILIARY CONSTANTS
$(A) = (a_1 + j a_2) = \cosh\theta = .870783 + j .021911$
$(B) = (b_1 + j b_2) = Z \frac{\sinh\theta}{\theta} = \sqrt{\frac{Z}{Y}} \sinh\theta = 34.5653 + j 206.83$ OHMS
$(C) = (c_1 + j c_2) = Y \frac{\sinh\theta}{\theta} = \frac{1}{\sqrt{\frac{Z}{Y}}} \sinh\theta = -.000,009 + j .001158$ MHO.
WHERE $\theta = \sqrt{ZY}$
TRANSFORMERS
(TWO BANKS IN PARALLEL AT EACH END OF THE LINE)
ON BASIS OF 100,000 KV-A RATING FOR TWO BANKS: RESISTANCE VOLTS = 0.658%; REACTANCE VOLTS = 8.225%; MAGNETIZING CURRENT = 5.300%; IRON LOSS = 0.705%
VALUES TO NEUTRAL
KV-A_{TN} = 33,333. E_{TN} = 127.020. I_{TN} = 262.4
$R_{TN} = \frac{.00658 \times 127,020}{262.4}$ = 3.185 OHMS RESISTANCE
$X_{TN} = \frac{.08225 \times 127,020}{262.4}$ = 39.82 OHMS REACTANCE
MAGNETIZING CURRENT = $\frac{.0530 \times 33,333,333}{127,020}$ = 13.9 AMPS AT 127,020 VOLTS
IRON LOSS = $\frac{.00705 \times 33,333,333}{127,020}$ = 1.85 AMPS AT 127,020 VOLTS
IRON LOSS = 235 KW TO NEUTRAL
I_S = 222.69 $\angle 37°38'01"$ AMPS.
θ_S = 17°26'26" PF_S = 95.403% LEADING
E_{SN} = 129.318 $\angle 20°11'35"$ VOLTS
132.787 VOLTS TO NEUTRAL—230,000 VOLTS BETWEEN CONDUCTORS
127.020 VOLTS TO NEUTRAL
IMPEDANCE OF H. T. LINE
CHARGING CURRENT OF H. T. LINE
I_{OO} = −1.14 + j 147.09
$E_{RN} \times c_2$
$I_R \times b_2$
$E_{RN} \times a_2$
$I_R \times b_1$
E_{RN} = 127.020 VOLTS
(VECTOR OF REFERENCE)
$E_{RN} \times a_1$
1.85 AMPS.
θ_R = 5°01'16" PF_R = 99.616% LAGGING
$E_{RN} \times c_1$
I_R = 204.17 $\angle 5°01'16"$ AMPS.
$I_R \times a_1$
$I_R \times a_2$
LEAKAGE OF LOWERING TRANSFORMERS
13.9 AMPS.
SYNCHRONOUS CONDENSERS
I_L = 231.55 $\angle 31°47'18"$ AMPS. (CORRESPONDS TO 85% PF LAGGING LOAD).
I_O = 118.09 AMPS.
4.72 AMPS.
118.00 AMPS
CALCULATION FOR RECEIVING-END CURRENT
I_L = 196.82 − j 121.97 AMPS. TO VECTOR E_{RN}
I_O = 4.72 + j 118.00
I_T = 1.85 − j 13.90
I_R = 203.39 − j 17.87
= 204.17 $\angle 5°01'16"$ AMPERES
CALCULATION FOR HIGH TENSION CIRCUIT
$E_{RN}(A)$ = 110.607 + j 2.783
$I_R(B)$ = 10.762 + j 41.856
E_{SN} = 121.369 + j 44.639
= 129.318 $\angle 20°11'35"$ VOLTS
$I_R(A)$ = 177.50 − j 11.11
$E_{RN}(C)$ = −1.14 + j 147.09
I_S = 176.36 + j 135.98
= 222.69 $\angle 37°38'01"$ AMPERES
KV-A_S = 129.318 × 222.69 × 3 = 86,393 PER 3 PHASE CIRCUIT
KV-A_{OO} = 129.318 × 147.09 × 3 = 57,064 PER 3 PHASE CIRCUIT
DETERMINATION OF LOSSES
KW_{LN} = 25.000
KW_{RN} = 127.020 × 204.17 (COS 5°01'16") = 25.835
KW_{SN} = 129.318 × 222.69 (COS 17°26'26") = 27.474
LOSSES TO NEUTRAL
CONDENSER = 600
LOWERING TRANSFORMERS (IRON LOSS) = 235
(COPPER LOSS 204.17² × 3.185) = 133
RAISING TRANSFORMERS (IRON LOSS) = 235
(COPPER LOSS) 222.69² × 3.185 = 158
HIGH TENSION LINE 27.474 − (25.835 + 133) = 1506
TOTAL LOSS TO NEUTRAL = 2867
EFFICIENCY
EFFICIENCY, (HIGH TENSION LINE) = $\frac{25.968}{27.474}$ = 94.52
EFFICIENCY, (GENERATORS TO LOAD) = $\frac{25.000}{27.867}$ = 89.71
% ERROR IN RESULTS
VOLTAGE AT SENDING END = − 1.93%
CURRENT AT SENDING END = + 1.06%
POWER FACTOR AT SENDING END = + 1.02%
KV-A AT SENDING END = − 0.88%
LOSS IN HIGH TENSION LINE = + 2.38%
NOTE—THESE PERCENTAGES OF ERROR ARE BASED UPON THE ASSUMPTION THAT THE COMPLETE METHOD PRODUCES 100% VALUES.—THE MINUS SIGNS SIGNIFY RESULTS TOO LOW; THE PLUS SIGNS RESULTS TOO HIGH.

FIG. 2

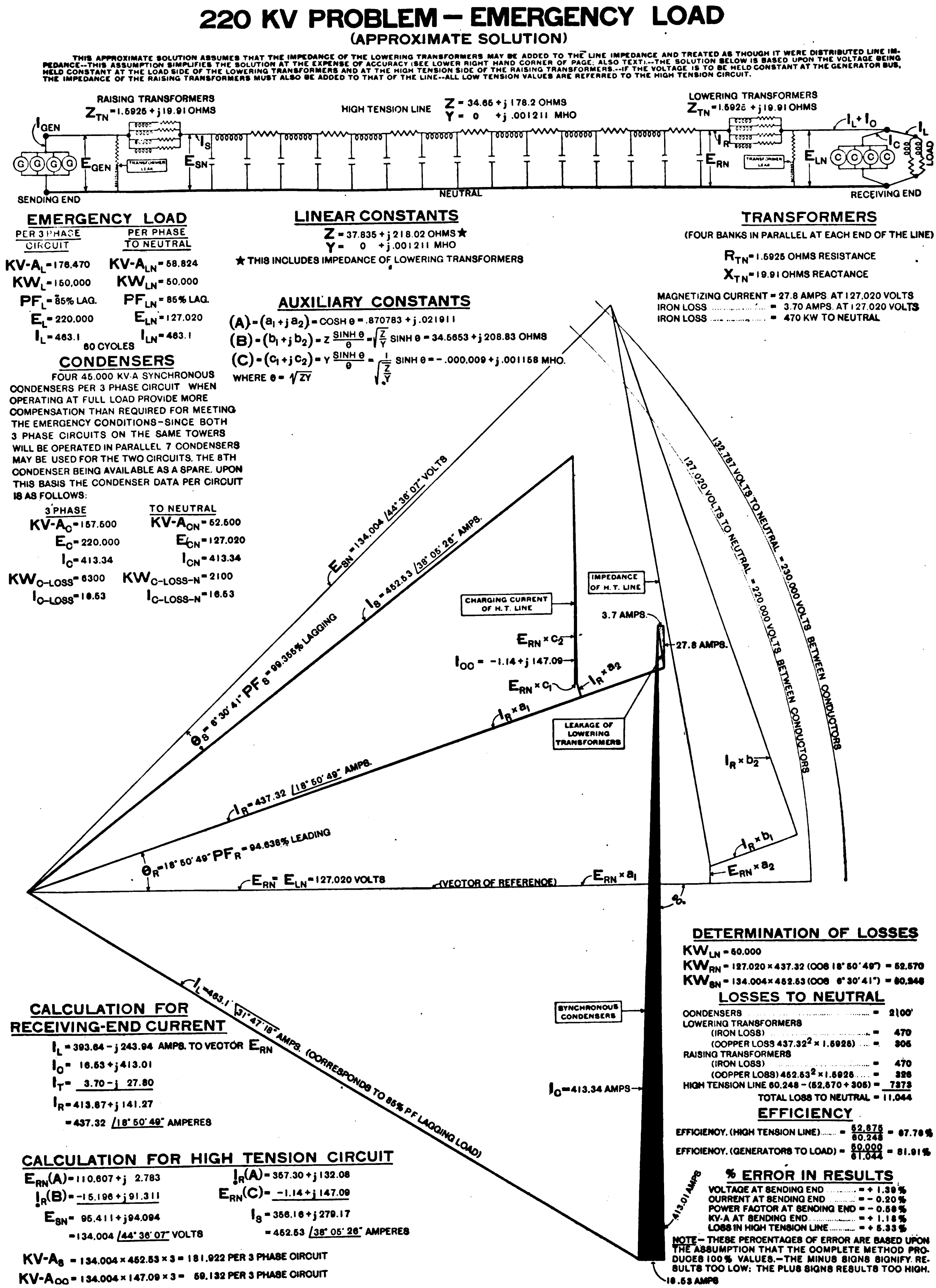
220 KV PROBLEM — EMERGENCY LOAD
(APPROXIMATE SOLUTION)
THIS APPROXIMATE SOLUTION ASSUMES THAT THE IMPEDANCE OF THE LOWERING TRANSFORMERS MAY BE ADDED TO THE LINE IMPEDANCE AND TREATED AS THOUGH IT WERE DISTRIBUTED LINE IMPEDANCE--THIS ASSUMPTION SIMPLIFIES THE SOLUTION AT THE EXPENSE OF ACCURACY (SEE LOWER RIGHT HAND CORNER OF PAGE; ALSO TEXT).--THE SOLUTION BELOW IS BASED UPON THE VOLTAGE BEING HELD CONSTANT AT THE LOAD SIDE OF THE LOWERING TRANSFORMERS AND AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS.--IF THE VOLTAGE IS TO BE HELD CONSTANT AT THE GENERATOR BUS, THE IMPEDANCE OF THE RAISING TRANSFORMERS MUST ALSO BE ADDED TO THAT OF THE LINE--ALL LOW TENSION VALUES ARE REFERRED TO THE HIGH TENSION CIRCUIT.
RAISING TRANSFORMERS
$Z_{TN} = 1.5925 + j19.91$ OHMS
HIGH TENSION LINE
$Z = 34.65 + j\,178.2$ OHMS
$Y = 0 + j\,.001211$ MHO
LOWERING TRANSFORMERS
$Z_{TN} = 1.5925 + j19.91$ OHMS
I_{GEN}
E_{GEN}
I_S
E_{SN}
I_R
E_{RN}
E_{LN}
$I_L + I_O$
I_L
I_C
LOAD
SENDING END
NEUTRAL
RECEIVING END
EMERGENCY LOAD
PER 3 PHASE CIRCUIT
PER PHASE TO NEUTRAL
$KV\text{-}A_L = 176.470$ $KV\text{-}A_{LN} = 58.824$
$KW_L = 150.000$ $KW_{LN} = 50.000$
$PF_L = 85\%$ LAG. $PF_{LN} = 85\%$ LAG.
$E_L = 220.000$ $E_{LN} = 127.020$
$I_L = 463.1$ $I_{LN} = 463.1$
60 CYCLES
CONDENSERS
FOUR 45.000 KV-A SYNCHRONOUS CONDENSERS PER 3 PHASE CIRCUIT WHEN OPERATING AT FULL LOAD PROVIDE MORE COMPENSATION THAN REQUIRED FOR MEETING THE EMERGENCY CONDITIONS—SINCE BOTH 3 PHASE CIRCUITS ON THE SAME TOWERS WILL BE OPERATED IN PARALLEL 7 CONDENSERS MAY BE USED FOR THE TWO CIRCUITS. THE 8TH CONDENSER BEING AVAILABLE AS A SPARE. UPON THIS BASIS THE CONDENSER DATA PER CIRCUIT IS AS FOLLOWS:
3 PHASE
TO NEUTRAL
$KV\text{-}A_O = 157.500$ $KV\text{-}A_{ON} = 52.500$
$E_C = 220.000$ $E_{CN} = 127.020$
$I_C = 413.34$ $I_{CN} = 413.34$
$KW_{C\text{-}LOSS} = 6300$ $KW_{C\text{-}LOSS\text{-}N} = 2100$
$I_{C\text{-}LOSS} = 16.53$ $I_{C\text{-}LOSS\text{-}N} = 16.53$
LINEAR CONSTANTS
$Z = 37.835 + j\,218.02$ OHMS ★
$Y = 0 + j\,.001211$ MHO
★ THIS INCLUDES IMPEDANCE OF LOWERING TRANSFORMERS
AUXILIARY CONSTANTS
$(A) = (a_1 + j\,a_2) = \cosh\theta = .870783 + j\,.021911$
$(B) = (b_1 + j\,b_2) = Z\,\frac{\sinh\theta}{\theta} = \sqrt{\frac{Z}{Y}}\,\sinh\theta = 34.5653 + j\,208.83$ OHMS
$(C) = (c_1 + j\,c_2) = Y\,\frac{\sinh\theta}{\theta} = \frac{1}{\sqrt{\frac{Z}{Y}}}\,\sinh\theta = -.000{,}009 + j\,.001158$ MHO.
WHERE $\theta = \sqrt{ZY}$
TRANSFORMERS
(FOUR BANKS IN PARALLEL AT EACH END OF THE LINE)
$R_{TN} = 1.5925$ OHMS RESISTANCE
$X_{TN} = 19.91$ OHMS REACTANCE
MAGNETIZING CURRENT = 27.8 AMPS. AT 127.020 VOLTS
IRON LOSS = 3.70 AMPS. AT 127.020 VOLTS
IRON LOSS = 470 KW TO NEUTRAL
$E_{SN} = 134.004$ /44° 36′ 07″ VOLTS
$I_S = 452.53$ /38° 05′ 26″ AMPS.
$\theta_S = 6°\,30'\,41''$ $PF_S = 99.355\%$ LAGGING
CHARGING CURRENT OF H. T. LINE
IMPEDANCE OF H. T. LINE
3.7 AMPS.
27.8 AMPS.
$E_{RN} \times c_2$
$I_{OO} = -1.14 + j\,147.09$
$E_{RN} \times c_1$
$I_R \times a_2$
$I_R \times a_1$
LEAKAGE OF LOWERING TRANSFORMERS
$I_R = 437.32$ /18° 50′ 49″ AMPS.
$\theta_R = 18°\,50'\,49''$ $PF_R = 94.638\%$ LEADING
$E_{RN} = E_{LN} = 127.020$ VOLTS
(VECTOR OF REFERENCE)
$E_{RN} \times a_1$
$I_R \times b_2$
$I_R \times b_1$
$E_{RN} \times a_2$
132.787 VOLTS TO NEUTRAL = 230.000 VOLTS BETWEEN CONDUCTORS
127.020 VOLTS TO NEUTRAL = 220.000 VOLTS BETWEEN CONDUCTORS
90°
$I_L = 463.1$ /31° 47′ 18″ AMPS. (CORRESPONDS TO 85% PF LAGGING LOAD)
SYNCHRONOUS CONDENSERS
$I_O = 413.34$ AMPS
413.01 AMPS
16.53 AMPS
CALCULATION FOR RECEIVING-END CURRENT
$I_L = 393.64 - j\,243.94$ AMPS. TO VECTOR E_{RN}
$I_O = 16.53 + j\,413.01$
$I_T = 3.70 - j\,27.80$
$I_R = 413.67 + j\,141.27$
$= 437.32$ /18° 50′ 49″ AMPERES
CALCULATION FOR HIGH TENSION CIRCUIT
$E_{RN}(A) = 110.607 + j\,2.783$
$I_R(B) = -15.196 + j\,91.311$
$E_{SN} = 95.411 + j\,94.094$
$= 134.004$ /44° 36′ 07″ VOLTS
$I_R(A) = 357.30 + j\,132.08$
$E_{RN}(C) = -1.14 + j\,147.09$
$I_S = 356.16 + j\,279.17$
$= 452.53$ /38° 05′ 26″ AMPERES
$KV\text{-}A_S = 134.004 \times 452.53 \times 3 = 181.922$ PER 3 PHASE CIRCUIT
$KV\text{-}A_{OO} = 134.004 \times 147.09 \times 3 = 59.132$ PER 3 PHASE CIRCUIT
DETERMINATION OF LOSSES
$KW_{LN} = 50.000$
$KW_{RN} = 127.020 \times 437.32\ (\cos 18°\,50'\,49'') = 52.570$
$KW_{SN} = 134.004 \times 452.53\ (\cos 6°\,30'\,41'') = 60.248$
LOSSES TO NEUTRAL
CONDENSERS = 2100
LOWERING TRANSFORMERS
(IRON LOSS) = 470
(COPPER LOSS $437.32^2 \times 1.5925$) = 305
RAISING TRANSFORMERS
(IRON LOSS) = 470
(COPPER LOSS) $452.53^2 \times 1.5925$ = 326
HIGH TENSION LINE 60.248 − (52.570 + 305) = 7373
TOTAL LOSS TO NEUTRAL = 11.044
EFFICIENCY
EFFICIENCY. (HIGH TENSION LINE) = $\frac{52.875}{60.248}$ = 87.76%
EFFICIENCY. (GENERATORS TO LOAD) = $\frac{50.000}{61.044}$ = 81.91%
% ERROR IN RESULTS
VOLTAGE AT SENDING END = + 1.39%
CURRENT AT SENDING END = − 0.20%
POWER FACTOR AT SENDING END = − 0.56%
KV-A AT SENDING END = + 1.18%
LOSS IN HIGH TENSION LINE = + 5.33%
NOTE— THESE PERCENTAGES OF ERROR ARE BASED UPON THE ASSUMPTION THAT THE COMPLETE METHOD PRODUCES 100% VALUES.—THE MINUS SIGNS SIGNIFY RESULTS TOO LOW; THE PLUS SIGNS RESULTS TOO HIGH.

FIG. 3

the same voltage (220 kv.) at both receiving and sending ends of the line about 20,000 kv-a. synchronous reactor capacity will be required as shown in Fig. 4.

Fig. 2 shows the performance of the system at normal load of 75,000 kw. per circuit and 220 kv. at the load. Under these conditions about 42,000-kv-a. synchronous condenser capacity will be required to hold receiving voltage at 220 kv. with an 85 per cent power factor load. If the voltage at sending end of the line is also held at 220 kv. with load conditions remaining the same, the synchronous condenser capacity required will be about 53,000 kv-a. as shown in Fig. 4.

Fig. 3 shows the performance of the system when emergency load of 150,000 kw. is carried by each circuit. This condition may exist for short intervals while one tower line is out of service for repairs. With

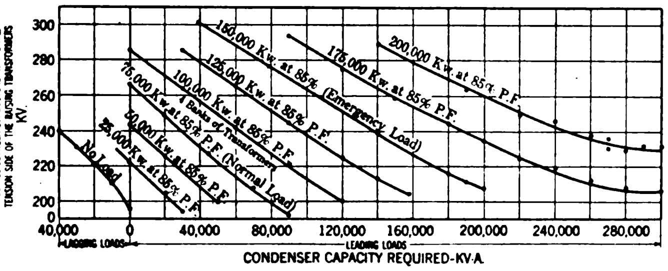

FIG. 4

230 kv. at sending end of line there will be required about 157,000 kv-a. synchronous condenser capacity to hold receiving voltage at 220 kv. with an 85 per cent power factor load. If voltage at sending end is also held at 220 kv. about 173,000-kv-a. condenser capacity will be required, as shown in Fig. 4.

Fig. 4 indicates, under various conditions of sending end voltage, the amount of energy which may be delivered to an 85 per cent lagging power factor load with 220 kv. at receiving end over this 225-mile, 60-cycle circuit consisting of three 605,000-cir. mil aluminum conductors. The synchronous condensers capacities corresponding to different sending end voltages are shown for various loads. It may be noted that with 230 kv. at sending end the maximum amount of power which can be transmitted over this circuit is about 200,000 kw. which will require synchronous condenser capacity at receiving end of about 300,000 kv-a.

The curve also shows that 25,000 kw. can be transmitted with about 222 kv. at sending end of line without any synchronous condenser capacity. It also shows that 75,000 kw. (normal load) could be transmitted with 266 kv. at sending end of line without any synchronous condenser capacity.

The following are the essential data on performance of some lines proposed for supply of energy to the superpower zone:

Power to be transmitted	300,000 kw.	300,000 kw.	300,000 kw.
Voltage at receiving end	220 kv.	220 kv.	220 kv.
Cycles	60	25	60
Length of line	350 mi.	350 mi.	115 mi.
No. of tower lines	2	2	2
No. of circuits per tower line	2	2	1
Size of conductors Aluminum	605,000 cir. mils	605,000 cir. mils	920,000 cir. mils
Steel	78,000 cir. mils	78,000 cir. mils	211,000 cir. mils
Normal load per circuit	75,000 kw.	75,000 kw.	150,000 kw.
Emergency load per circuit	150,000	150,000	300,000
Power factor of load	85 per cent	85 per cent	85 per cent
Power factor gen. end (normal load)	0.893 ld	0.884 ld	0.93 lg
Power factor rec. end (normal load)	0.983 lg	0.934 ld	0.97 lg.
Power factor gen. end (emergency load)	0.983 lg.	0.983 lg.	0.91 lg.
Power factor rec. end (emergency load)	0.879 ld.	0.894 ld.	0.98 ld.
Synchronous condenser capacity required (normal load)	152,000 kv-a.	90,000	141,000 kv-a.
Line losses (normal load)	29,800 kw.	36,360 kw.	13,800 kw.
Transformer core losses (normal load)	4,500 kw.	6,000 kw.	4,500 kw.
Synchronous condenser losses (normal load)	6,100 kw.	3,600 kw.	5,640 kw.
Total losses (normal load)	40,000 kw.	45,960 kw.	23,940 kw.
Efficiency of transmissions (normal load)	88.1 per cent	86.7 per cent	92.6 per cent

It may be of interest to note that in the 60-cycle, 350-mile line, with voltage held the same at both ends, the voltage in the middle of the line is approximately 6 per cent higher than at either end. In the 25-cycle line under similar conditions the "bulge" is only about 1 per cent.

The proper design of a transmission system requires special and thorough knowledge of the physical conditions to be met both in construction and operation of the line. The following points are applicable to all long-distance transmission systems:

(1) The right of way must be of ample width, in order that the conductors may be adequately spaced and so that there may be no danger of the conductors of adjacent lines coming in contact with each other. The right of way must be kept cleared so that growing trees cannot possibly come in contact with the conductors. Standing trees must be left so far away that when felled they do not reach the lines. Transmission lines have often been greatly hampered by inadequate rights of way; owners have had to be content with grants for use of public highways, or to make such terms as they could with private owners. In many cases easements could be obtained only on the basis that trees should not be trimmed except by special consent of the owners. This has resulted in many crooked lines, every bend involving a hazard. A transmission line of the magnitude we are considering is often a more important carrier than a railroad, and there should be laws granting the right of expropriation so that a right of way may be obtained commensurate with the importance of the service which it must render to the public. The lines should change direction as infrequently as possible, even slight curves should be avoided wherever possible. On account

of the expense and hazard involved in dead end angle towers tangents must be as long as the character of the country will permit. Wherever possible the right of way should be located away from cultivated areas, as the lines will then be less subject to interference from the activities of the people and the cost of the land will not be so great. Lines should not parallel railroads or communication circuits of any kind if this can be avoided.

(2) The transmission line should consist of steel towers with maximum spacing consistent with strength of conductors and most economical cost. For conductors of moderate size and under the usual assumptions as to limiting conditions of tower spacing will be as follows: For hard drawn copper about 800 feet, for steel reinforced copper about 1000 feet; for steel reinforced aluminum cables this may be increased to about 1500 feet. The configuration of the ground will probably call for many shorter or longer spans but these should be avoided when possible. Few towers mean few insulators, each of which is necessarily a danger point. The conductors for the 220,000 volt lines should be spaced at least 18-ft. delta, or its equivalent, but 21-ft. spacing is better. If vertical spacing is adopted the conductors should be staggered so that ice falling from one conductor may not cause a short circuit with the conductor below it. In areas where sleet prevails this matter must be given careful attention. Authentic records exist of sleet forming over 1½ inches in radial thickness on line conductors. In case the transmission line lies wholly within a sleet area the cost of construction to withstand this extreme loading may be prohibitive. In this case provision should be made so that during a sleet storm one or more of the circuits may be loaded until they are warm enough that ice will not form on them. The remaining line, or lines should be short-circuited and separate generators used to send enough current through them to keep them warm. This method has been used by one large transmission company for several years with entire success. In this way the lines may be preserved through a severe sleet storm and kept ready for service although it may be somewhat hampered while the storm lasts. With proper patrol organization the stations at the ends of the line should be kept informed of climatic conditions along the line at all times.

Clearance between conductors and towers should be such that with maximum wind deflection there will be no flash-over to ground. In the past this has been one of the most frequent causes of interruption to service.

(3) The strings of strain insulators should be graded or other means provided so that excessive voltage strains do not come on the units nearest the conductors, when lines are operated at 220,000 volts or higher. The writer sees no great objection to grading the disks, and a fairly even distribution of potential among the insulator units can be obtained in this way. It has been objected that linemen will not pay attention to orders and will install the first unit that comes to hand when it is necessary to make a replacement. After twenty years' experience in operating and maintaining transmission lines the writer believes that this is not a valid objection and that effective organization will prevent such happenings.

(4) Switching must be reduced to its lowest terms. There should be no taps from the transmission line between the step-up transformers at the generating station and the step-down transformers at the point of delivery. Where possible, switching should be done on the low-tension side of the transformers but a certain amount of switching to shift the load from one circuit to another on high-tension lines will be unavoidable. Manufacturers have successfully provided oil switches for 150,000-volt circuits involving comparatively large amounts of power, and switches for 220 kv. circuits will have no heavier duty as the currents are smaller. High reactance inherent in transformers and lines contribute to limiting the currents at time of short circuit to comparatively small amount, thus minimizing the duty imposed on oil switches.

(5) Neither overhead ground wires nor lightning arresters should be provided on circuits of 220,000 volts or higher as it is believed they will cause more trouble than they will prevent. Induced high-frequency charges will be absorbed by the large capacity of the lines and dissipated by corona.

While it is essential that the transmission system be properly designed and constructed, and that the physical conditions surrounding the line be under control of the operating company, the operating organization is of even greater importance. Years are required in which to build up an operating personnel which will get the best service from a transmission system. Eternal vigilance is the price of service, and this can be obtained only with an intelligent, loyal, well trained and well paid operating staff.

The Service That Can Be Expected From Long-Distance Transmission

Continuity of service cannot be readily evaluated. In a densely settled community where many thousands of people are entirely dependent on the public utility systems for light, power and transportation, it is customary to set a high value on continuity of service. Public utility companies have gone on the principle that absolute continuity of service, so far as humanly possible, is necessary, and they have provided large excess of generating capacity and duplicate feeder systems at great expense to accomplish this result. The utility manager has in mind the multitude of complaints that arise whenever an interruption to service, however slight, occurs and however small this inconvenience to the company's patrons

may have been. Human nature, in this age of rushing effort to accomplish work in its frantic pursuit of pleasure, is impatient at delay. An insignificant interruption to traffic in New York caused by failure of power supply furnishes opportunity for much complaint and publicity in the newspapers all of which is very embarrassing to the utility companies. It must be admitted that much of this frenzy for haste is infectious and is contracted from seeing others so impelled and not from any necessity in the case. Subway and elevated trains must be on time. The commuter hastens to his suburb only to sit down and read the paper for an hour before dinner. Broadway must be brilliantly lighted with thousands of lights every minute of every evening or the crowds are disappointed. In short the service must be perfect.

In some parts of our country large amounts of energy for transportation, power and lighting are brought from power plants located at waterfalls in the mountains. The people understand this and know of the various climatic and other elements beyond human control that may effect this service. A few times in a year there may be interruptions to the service. They do not like it but it is expected, no one is perceptibly the worse for it, and life goes on as usual. Now if these communities were to have the service demanded by New York City, there would have to be large reserves in generating plants, possibly steam plants in the cities would be required, the transmission lines would have to be duplicated and perhaps built along different routes and many other safeguards taken at very great expense. The people would have to pay the cost which might easily be double the price they are now paying for energy. Can they afford it? New York demands perfect service and, generally speaking, gets it. New York also pays for it. Can she afford it? Like many other things in New York the people pay for this superservice whether they can afford it or not.

The standard of service now given by many of our long-distance plants is not the best that can be attained for there is not one of these, if it were to be rebuilt at the present time, that could not improve its service, although the present standard is high and is being steadily improved. New long-distance lines now building are taking advantage of past experience and increased knowledge of the causes of trouble and means of preventing it. One of the reasons for trouble experienced in the past is that the developing companies were hampered by financial limitations. They could not build as well as they knew how for lack of money and had to do the best they could with the means available. When a plant is once built and in operation it is very difficult to raise additional money solely for the purpose of improving the service, and without expectation of increased revenue. Material improvement in service would generally mean entire reconstruction of the transmission lines and the earning power of very few plants would stand the additional cost.

In order to secure the opinion of those most favorably situated to judge as to whether energy transmitted over long lines can be delivered with the continuity necessary to satisfy the requirements of users of energy in the Superpower Zone, a series of questions were propounded to them premised by the assumption that the energy should be transmitted from either steam or hydroelectric stations ranging from 100,000 to 300,000 kw. in capacity over transmission lines of the highest grade of construction distances ranging from 100 to 300 miles.

Sixteen answers were received from prominent men holding responsible positions either as consulting or operating engineers of companies operating long-distance transmission lines in this country. These men, as well as the history of the transmission systems they are identified with, are well-known to engineers.

The answers received naturally reflected the experiences of the companies which these engineers represent. However, leaving out of account the psychology of the matter as affecting their answers there was practical unanimity of opinion that two tower lines, each supporting two circuits, each tower line with its circuits being capable in emergency of transmitting the entire load, would reasonably insure continuity of service of the character required by the metropolitan district of New York.

Long-distance transmission plants are not the only ones subject to interruptions. Local steam-electric plants are also subject to interruptions from storms, strikes, freight blockades, and from other causes. The remedy for this is numerous and varied sources of supply and interconnection of plants. This is now being carried out locally in various parts of the country particularly in New England, the south Atlantic states and in California, and is the method being proposed on a large scale by the Superpower Survey in the Washington-Boston district. When the whole country is connected with a large network of interconnecting lines between load centers, and these load centers are arranged for supply from local steam stations, large steam stations in neighboring cities, steam stations at the mines, and hydroelectric stations from sites both far and near, continuity of service will be assured far beyond what can be obtained from any single or local source of supply, however well safeguarded. The communities will then be practically independent of strikes or storms or meteorological conditions and will have better and more reliable service than can be obtained in any other way.

The author wishes to acknowledge the assistance of Messrs. William Nesbit, P. H. Thomas, and P. M. Lincoln, in preparing the diagrams and in the calculations, the results of which are given in this paper.

Carrier Current Telephony and Telegraphy

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Western Electric Co. American Telephone & Telegraph Co.

Concluded from page 421 of JOURNAL for May, 1921.

Commercial Apparatus and Installations

Under this section there is given a description of the apparatus which has been developed for commercial service and of the manner of employing it in actual installations in the Bell Telephone Plant. To date there have been developed and put into commercial use, three distinct types of multiplex carrier systems, as follows:

1. A carrier telephone system in which the carrier is transmitted.
2. A carrier telephone system in which the carrier is suppressed.
3. A carrier telegraph system

There has also been developed a two-way repeater set employing vacuum tubes, and suitable for use with any one of these three systems.

We will consider these systems in the order noted above, including the repeater more specifically under the first system, and will then discuss the general considerations as to their practical uses which are common to all the systems.

Carrier Telephone System Employing Transmitted Carrier. The apparatus which characterizes this type of system is indicated diagrammatically in Fig. 42, which shows the terminal circuit arrangement of one two-way channel.

This circuit can perhaps be most simply explained by tracing the path of currents involved in telephone transmission, which is shown by heavy lines in the figure. Voice frequency currents originating in the low-frequency line on the left pass through the low-frequency hybrid coil, *L H*, into the vacuum-tube modulator, *M*. There is likewise fed into the modulator the carrier current from the vacuum-tube oscillator, *O*, shown in light lines. Of the components of modulation appearing in the output circuit of the modulator, the transmitting band-filter, *T F*, suppresses all except one side band, either the upper or lower as desired, and the carrier, which it transmits or passes into the circuit common to all of the transmitting channels. The transmitting currents from this and the other channels then pass through the carrier hybrid coil and out on the carrier line.

The balancing networks, *L N* and *C N*, shown in Fig. 42, are important elements in determining the satisfactory operation of the system. The network, *L N*, on the left balances the low-frequency line and is similar to those used in ordinary telephone-repeater practise. The network, *C N*, on the right is of the type discussed above in the section on lines, and is illustrated in Fig. 35. It includes apparatus for balancing the office cabling and the line filters as well as the line itself.

The currents received from the line, which in the case of any given channel consist of one side band accompanied by its carrier, pass through the carrier hybrid coil and are selectively passed to the appropriate receiving circuits by means of the receiving

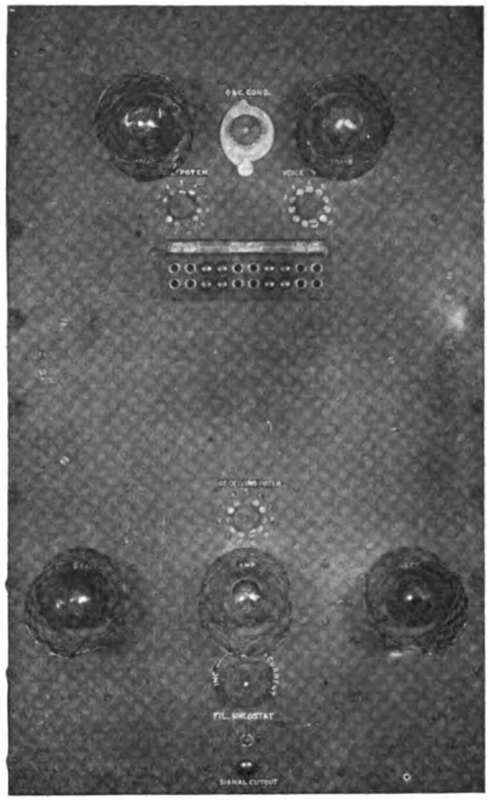

Fig. 43

band filters, one of which is shown at *R F*. The current passing through the filter *R F* is then amplified and demodulated in the two-stage vacuum-tube unit, *A D*, and the voice frequency currents appearing in the output circuit are selected from the other components of demodulation by the low-pass filter, from which point in the circuit they pass through the low-frequency hybrid coil, *L H*, to the connecting voice frequency line.

It should be pointed out that Fig. 42 indicates the points of connection for the transmitting and receiving circuits of the other two-way channels of the multiplex system, which are led to additional low-frequency lines through sets of apparatus which are exact dupli-

cates of the one shown, except for the modifications necessitated by the use of different frequencies over the different channels.

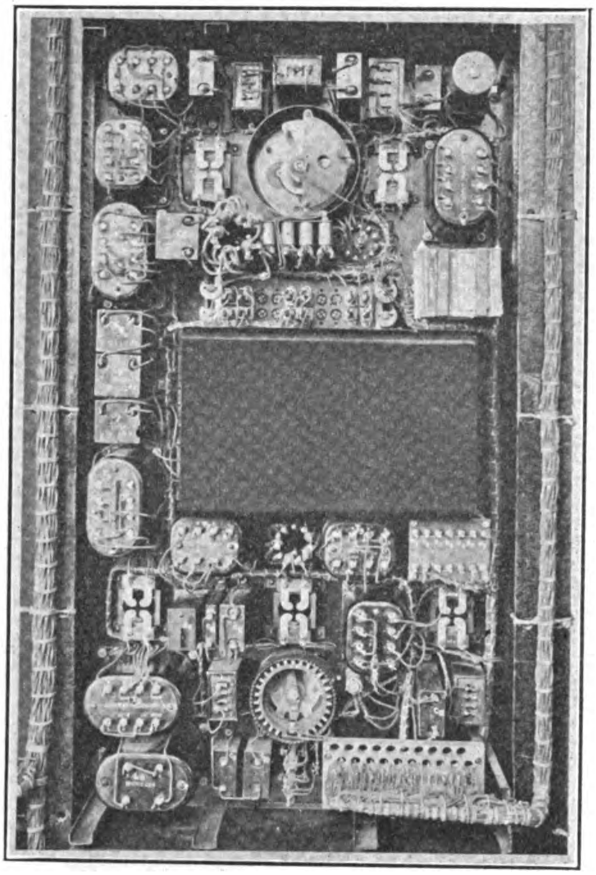

Fig. 44

The relays and the rectifier, employed in signaling by the methods already discussed, are also shown in the figure in light lines.

For convenience the apparatus itself is mounted on panels which are attached to relay racks in the central offices. The vacuum tubes peculiar to a two-way channel along with their immediately associated coils and other apparatus, are mounted on a panel by themselves, front and back views of which are shown in Figs. 43 and 44. At the top of Fig. 43 may be seen the oscillator and modulator tubes mechanically protected by wire cages, the control and dial of the condenser for adjusting the frequency of the oscillator, and similarly the potentiometers for controlling the supply of carrier and voice currents to the modulator. The jacks facilitate access to the various portions of the circuit for testing purposes. Below are shown the three vacuum tubes of the receiving circuit, the potentiometer for controlling the line current supplied to the detector input, the filament-current rheostat and a signal lamp with cut-out key. The remainder of the apparatus is mounted on the back of the panel, Fig. 44, and when installed is protected by metal covers.

An assembly of panels of the type just described, each associated with an individual carrier telephone channel, together with other apparatus about to be described, is shown in Fig. 45. At the left may be

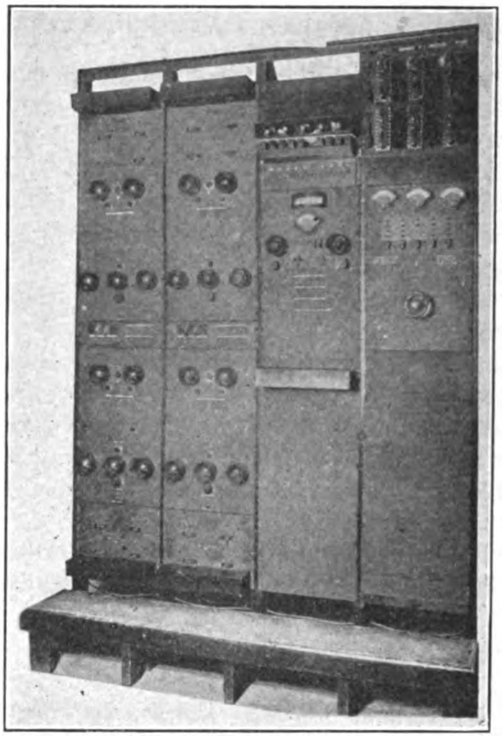

Fig. 45

seen four of the panels, three working in this instance and one spare, such as were shown in Fig. 43. The band-filters discussed above are mounted as individual units, of one of which a photograph is shown in Fig. 46. The coils and condensers are shown secured to a mounting plate; and this plate is clamped to the

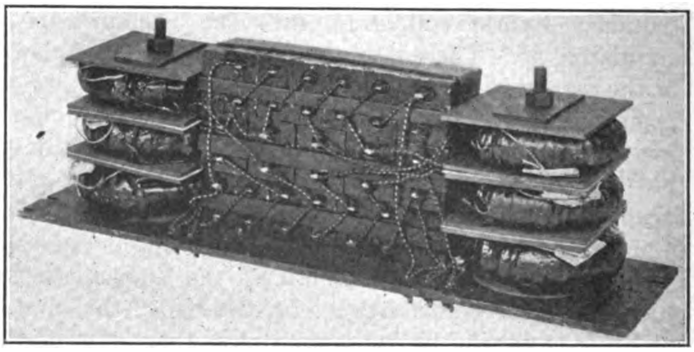

Fig. 46

vertical rack immediately adjacent to the vacuum-tube panel with which it is electrically associated. In Fig. 45 these filter-units may be seen located just above and below the vacuum-tube panels. In the two bavs to the right are mounted the apparatus controlling the power supply to the tubes, the apparatus used in the routine maintenance tests, and the hybrid coils and signaling relays.

The repeater set, which can be used with any of the carrier systems so far employed, embodies the circuits shown in Fig. 22. A front view of an actual set is

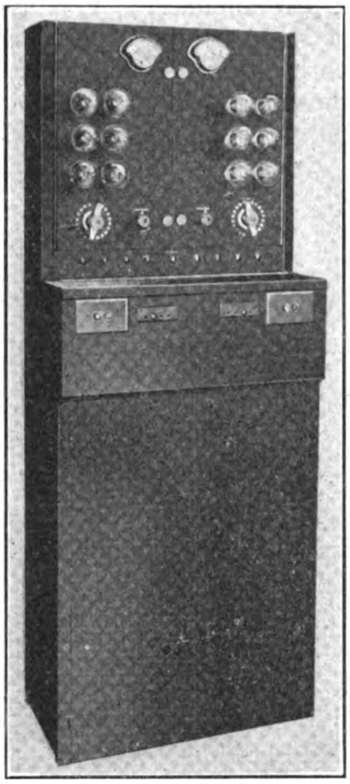

Fig. 47

shown in Fig. 47. This set includes the two-stage push-pull amplifiers, one for operating in each direction, and the necessary filters and hybrid coils for associating the set with the line. The balancing networks are located on shelves of a nearby rack. Also there is furnished a testing unit which may be associated with a number of such repeaters, usually up to four.

An illustration of an installation of this type is afforded by the Harrisburg-Detroit system, which is planned for New York-Detroit telephone service. A diagrammatic layout of this system is given in Fig. 48.

The carrier terminals are located at Detroit and Harrisburg, and the three carrier channels are brought from Harrisburg into New York as voice frequency circuits of the four-wire cable type. The system is provided with three intermediate repeaters at the points indicated. An additional open wire circuit between Harrisburg and Detroit is equipped with the necessary line filters at the terminals and the intermediate points, to make it readily available as a spare line-circuit. This spare line-circuit may be employed subsequently for a second carrier system. In its course from Harrisburg to Detroit the carrier system is superimposed upon two different voice frequency circuits in turn. One of these is a New York-Chicago circuit, which the carrier system takes between Harrisburg and Beaver Dam, at which point it deviates from the route pursued by the carrier system. The remaining portion follows a different voice frequency circuit from Beaver Dam to Detroit. This illustrates the possibility of transferring the carrier systems from one voice frequency circuit to another en route. The separation of the carrier channels from the regular voice frequency channel, at each of the intermediate points, enables the two sets of channels to be handled entirely independently of each other in their operation and maintenance. For example, at Pittsburgh a

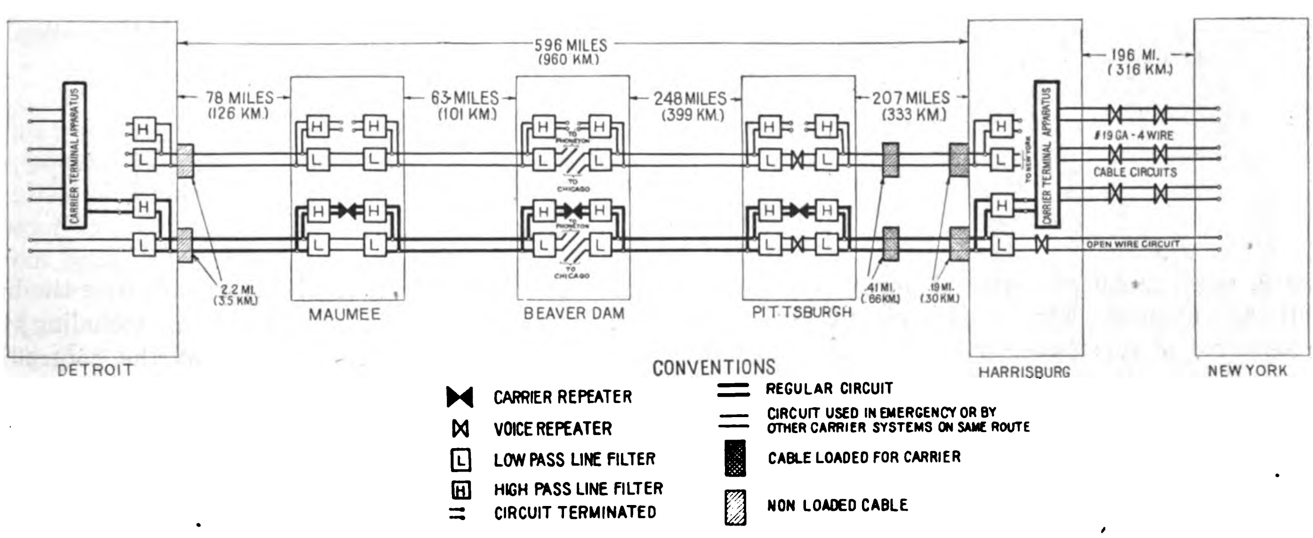

Fig. 48

repeater is inserted in the voice frequency circuit as well as in the carrier frequency channels, while at Beaver Dam and Maumee the repeaters are inserted in the carrier channels only. The occurrence of sec-

tions of intermediate cable in the system is indicated in the figure. The effect of the cable sections between Harrisburg and Pittsburgh was specifically referred to in the section on Lines.

Carrier Telephone System with Suppressed Carrier. The second type of carrier telephone system has been designed to operate on the principles of carrier suppression and harmonic carrier generation which were quite fully discussed above. In comparison with the system just described it is rather more complex and the base-frequency amplifier which selectively amplifies this frequency and supplies it to the line as shown. In the transmission circuit it will be noted that in addition to the balanced modulator, *M*, already described, a push-pull amplifier, *T A*, is used to increase the volume of side-band current transmitted. The high-pass filter between the modulator, *M*, and amplifier, *T A*, prevents the latter from being overloaded by the voice currents in the output of the modulator. The balanced demodulator, *D M*, serves to prevent

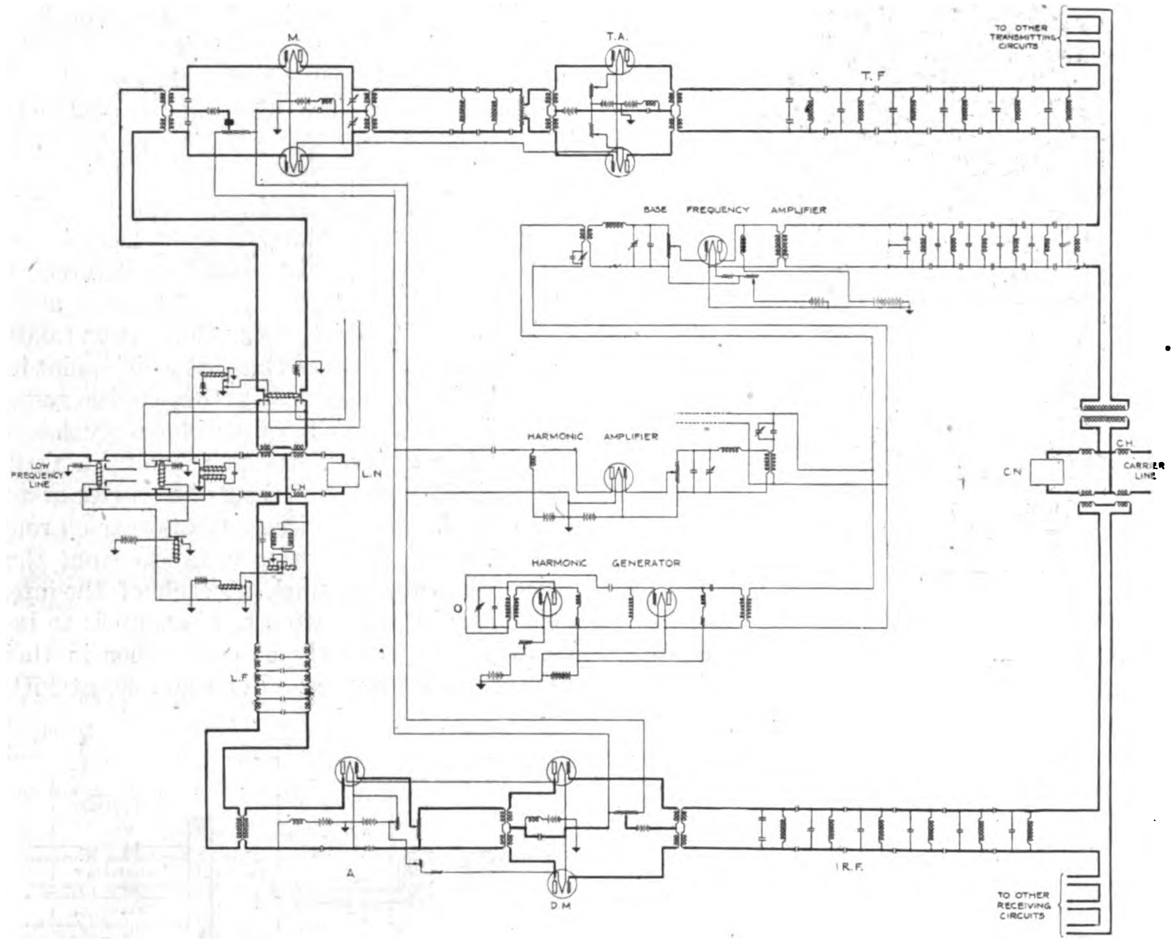

Fig. 49

there is more auxiliary terminal apparatus common to all the channels. Fig. 49 is a circuit diagram of one terminal of one two-way channel together with the common carrier-supply circuits. As usual, the transmission circuits are indicated by heavy lines, while the light lines show the carrier-supply and the signaling. The system indicated is one designed to use the same carrier frequency for both directions of a two-way conversation. Therefore the harmonic generator is shown as feeding through the same selective circuit and harmonic amplifier, into the modulator, *M*, and the demodulator, *D M*. The harmonic generator is supplied with the base frequency from the oscillator, *O*, and in addition to supplying the harmonics it also supplies the base frequency to the terminals of the transmission of the local carrier back over the line. The carrier-supply apparatus shown, including the harmonic generator, is that used at the controlling station. At the distant station the arrangement is modified to provide for amplifying the base frequency received from the incoming carrier line and supplying it to a harmonic generator which supplies the various frequencies through the amplifier to the modulators and demodulators associated with each channel.

The apparatus for this system has been mounted on unit racks of self-supporting type. One such unit holds the sending apparatus for one channel and another the receiving apparatus. Illustrations of these are shown in Figs. 50 and 51. Apparatus such as tubes

and potentiometers is located with convenient accessibility and the space below is used for filters, condensers and other apparatus which requires practically no attention or adjustment. Similar racks are used for the base-frequency oscillator and harmonic generator, the harmonic amplifiers, the testing circuits and the auxiliary low-frequency apparatus.

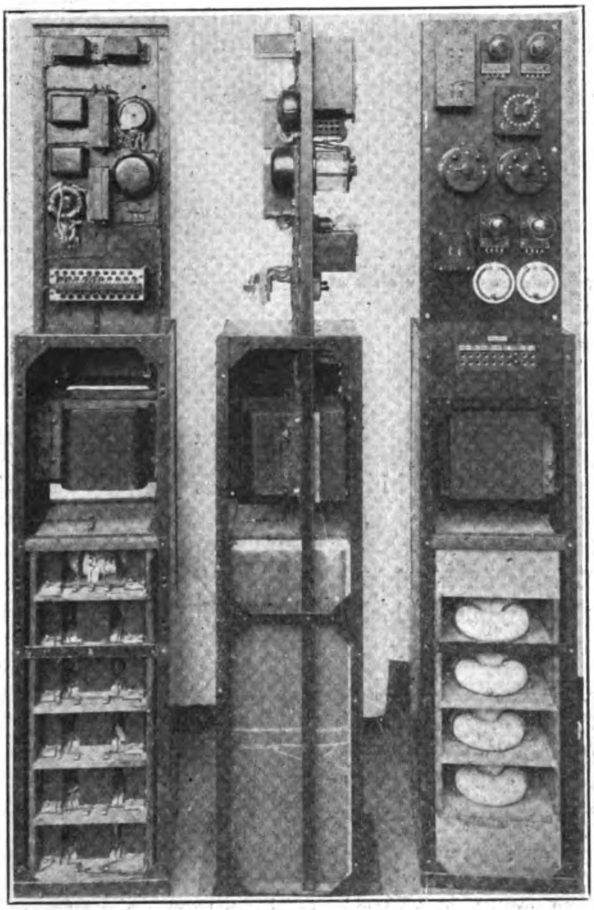

Fig. 50

This type of apparatus is employed, for example, in the Harrisburg-Chicago system, the circuits of which are extended into New York as voice frequency circuits in order to provide New York-Chicago service. This system spans a somewhat greater distance than the Harrisburg-Detroit and includes four intermediate carrier repeater stations. Fig. 52 shows diagrammatically the layout of the whole system. For insurance of service a second set of line wires is arranged for carrier operation as illustrated. In general the plant features are the same as in the case of the Harrisburg-Detroit installation above. Because each carrier circuit in this system employs the same carrier frequency for transmission in the two directions, greater care was taken to make the lines of uniform impedance and to simulate them with their associated balancing networks.

In the Harrisburg-Pittsburgh section, this system is operated over the same pole line as is the one previously described and also with a multiplex carrier telegraph, later referred to. This has required a special transposing of the line wires between these two points.

The appearance of the apparatus at the terminal offices is shown by Fig. 53, which is that located at the Chicago terminal. In the center of the group of panels is seen the test panel by means of which the routine maintenance tests of the apparatus and lines are made.

A typical repeater installation at an intermediate office is shown in Fig. 54, which is that located at Cleveland. Two repeater units, one a spare unit, are provided; and located beside them is the testing unit employed for maintenance tests and switching.

Carrier Telegraph System. The fundamental circuit of a carrier telegraph channel has already been shown in simplified form by Fig. 23. Fig. 55 shows the circuits for associating ordinary telegraph sending and receiving loops with one terminal of a duplex carrier telegraph channel. It also shows

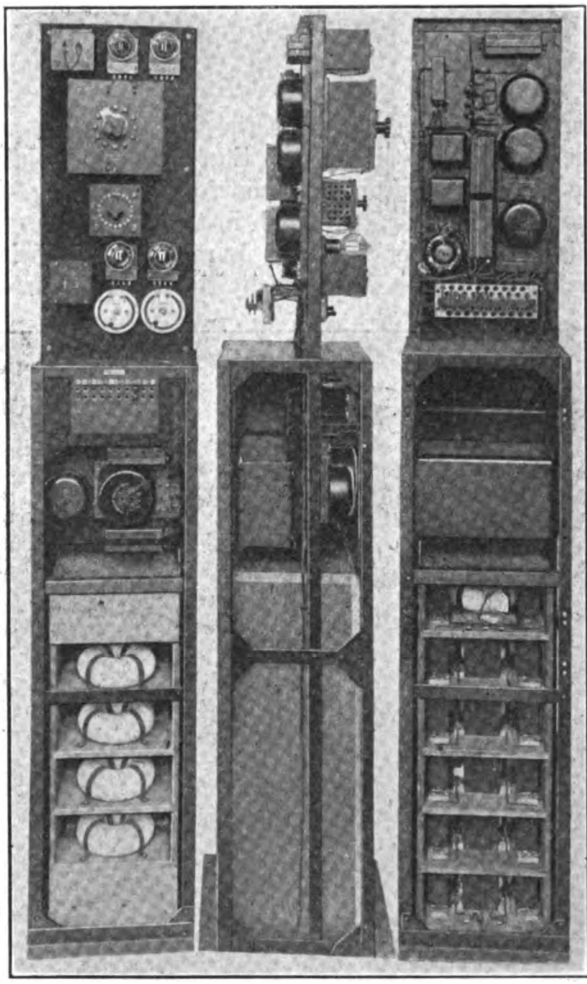

Fig. 51

schematically the high-frequency side of the system including the selective circuits and the vacuum-tube apparatus. The operation of the high-frequency side of the system will be clear from a consideration of the simplified telegraph circuit and from what has been said of the operation of the very similar carrier telephone apparatus. It may be said, however, that the

discrimination by tuned circuits between the sending and receiving channels which are of different frequencies is supplemented by the line-balancing arrangement shown, as in the telephone system first described above.

mounted on a self-supporting rack Fig. 56. On the front of the panel may be seen the vacuum tubes, the meters for observing the signaling currents, the sounders and key for monitoring, and the switches

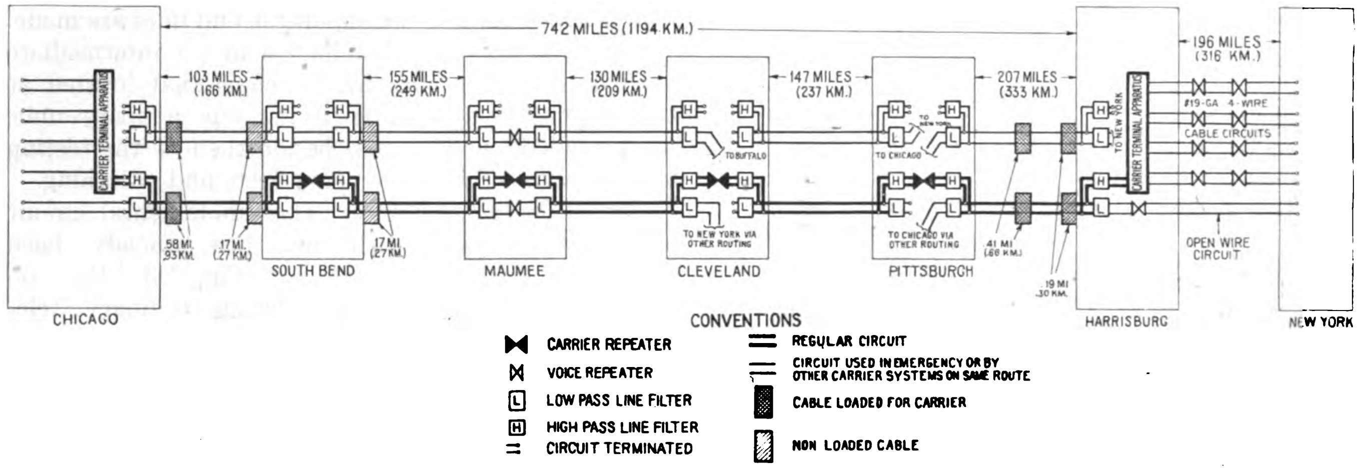

Fig. 52

Referring to the operation of the low-frequency side of the system, it will be seen that the manipulation of the sending operator's key controls the sending relay of the carrier apparatus which in turn impresses the signals on the carrier current. In receiving, a sensitive polar relay is shown, operated by the rectified current,

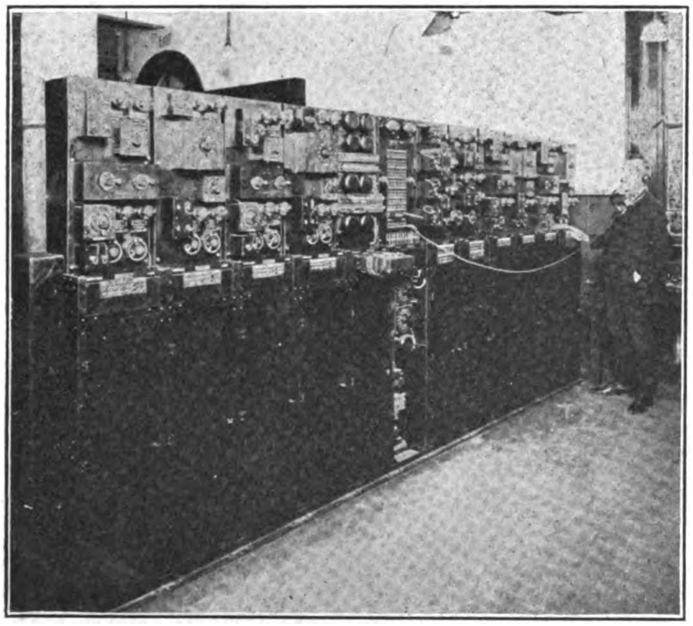

Fig. 53

which in turn transmits the signals into the local subscriber's loop in the form of the usual direct-current impulses. In the actual apparatus switches are provided by means of which the sending and receiving channels are associated with a common subscriber-loop for half-duplex operation.

The apparatus for one terminal of one full-duplex carrier telegraph channel, represented in Fig. 55, is

associated with the subscriber's loop circuit. The panel at the top is hinged to afford ready access to the apparatus mounted on the back. In the lower compartment are located the tuned circuits, the adjustable condensers of which are visible. Below these can be seen the cylindrical case which contains the sensitive receiving polar relay.

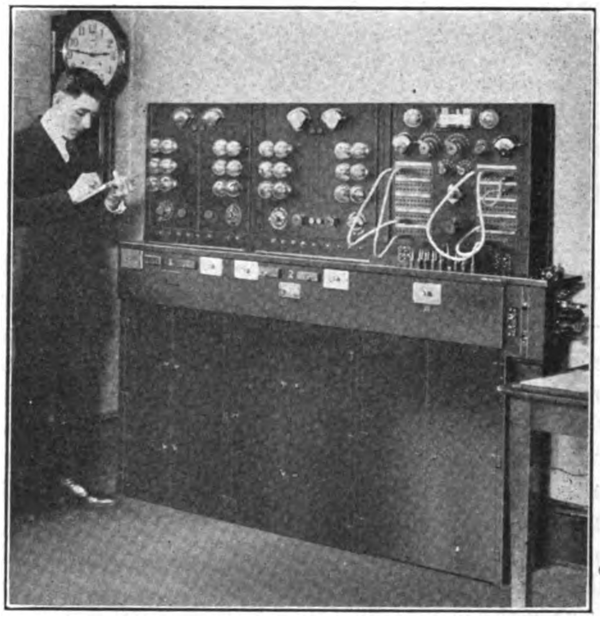

Fig. 54

Fig. 57 shows a group of carrier telegraph sets with an associated testing unit constituting a part of a complete installation located at Pittsburgh. At the top of the testing unit may be seen the relay and sounder of a regular test wire which extends along the route taken by the carrier system, a meter for measuring high-frequency line currents and the dials associated

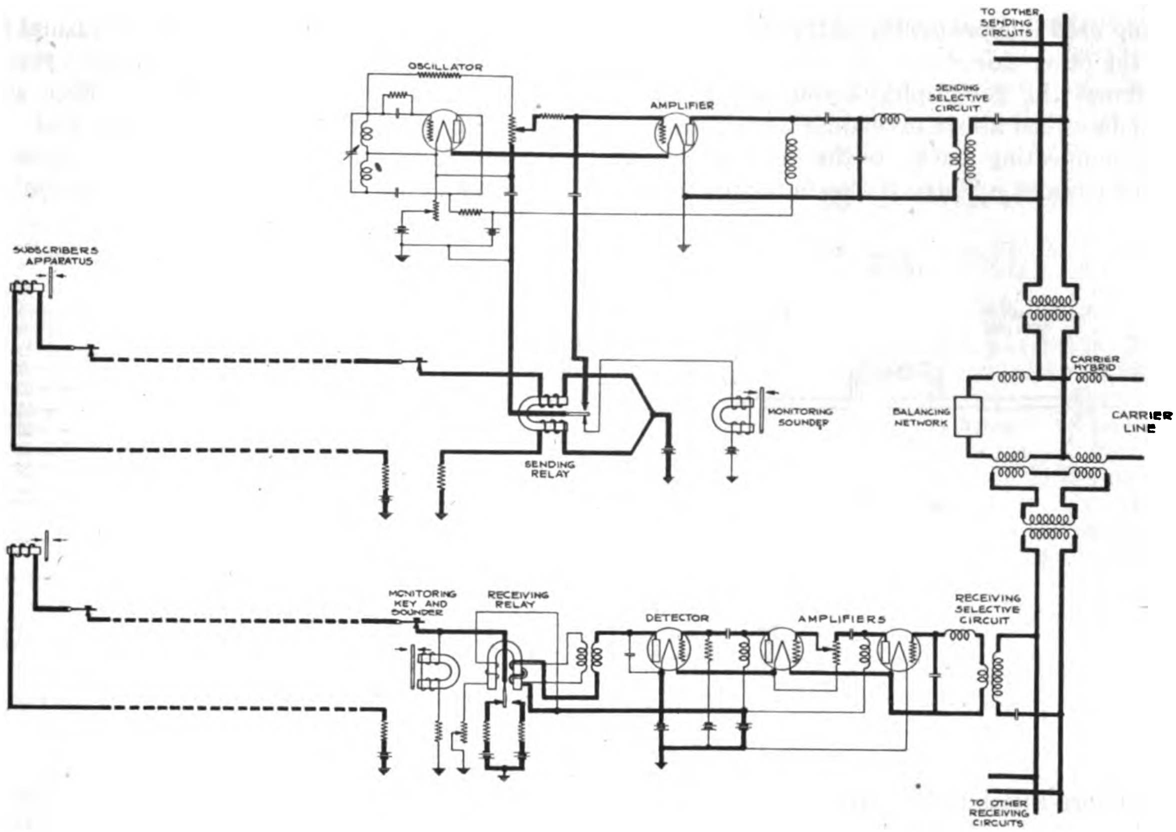

Fig. 55

with an oscillator for testing purposes. The jacks afford access to circuits of any of the carrier telegraph panels grouped with the test unit.

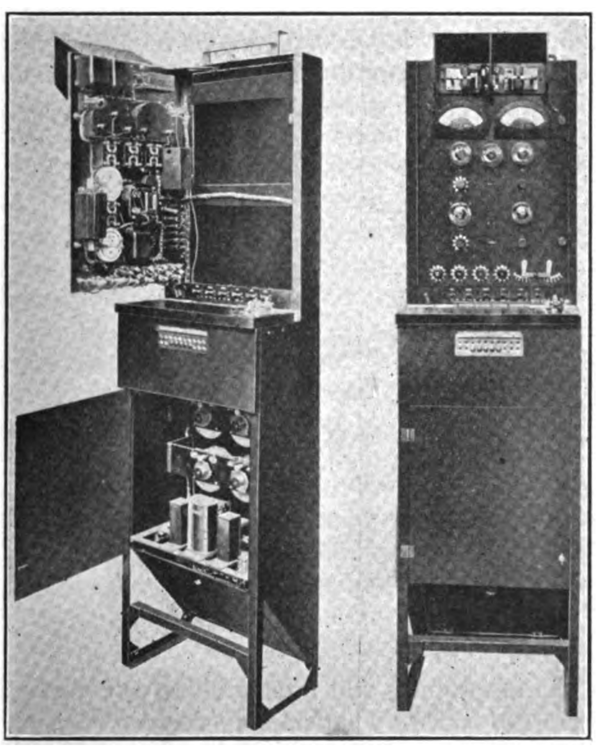

Fig. 56

The layout of the ten-channel Harrisburg-Chicago carrier telegraph system which includes the equipment of Fig. 57 is shown in Fig. 58. The circuits connecting the Harrisburg terminal to New York, where the most of the telegraph business terminates, are also shown. Pittsburgh, it will be noted, is not made merely a repeater station, as is Beaver Dam, but instead is

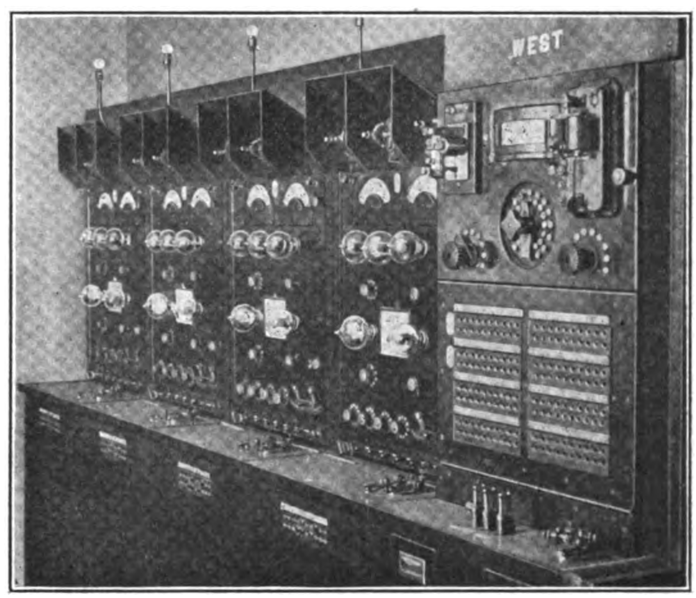

Fig. 57

equipped with two complete sets of carrier telegraph terminal apparatus. This is done to permit of connection between the through channels and local telegraph loops and also to permit of any one channel on

one side being used independently of the corresponding channel on the other side.

Fig. 59 shows the geographic layout of the three installations described above extending west from Harrisburg and connecting back to the seaboard cities through cable circuits. There is also indicated on this map the Baltimore-Pittsburgh telephone system, which was originally installed for giving Washington-Pittsburgh service.

General Considerations. An important aspect of the carrier developments described above is that they have placed the art upon a quantitative basis and enabled carrier installations to be engineered and put into operation in much the same way as is done for regular repeater telephone circuits. The transmission layout of the system is determined from a consideration of data on line characteristics and from the characteristics of the apparatus. In carrying out an installation, a certain amount of preparatory work must usually be done on the lines, including particularly the loading of intermediate sections of cable and transposition work. In the offices, the apparatus is installed in much the same way as are the more usual forms of telephone equipment, taking certain precautions, however, to minimize the lengths of office wiring included in the high-frequency circuits and to avoid cross-talk in the wiring interconnecting the individual apparatus units. The battery supply currents for the vacuum tubes are usually furnished from the existing 24-volt telephone batteries and 120-volt Morse batteries.

The grade of service given by carrier circuits, both telephone and telegraph, is as a rule quite up to the high standards which prevail for the long-distance circuits of the Bell plant. Not only is it possible to deliver the volume of transmission necessary for enabling the carrier circuits to be greatly extended by the addition of ordinary circuits at the ends, but also the naturalness and intelligibility of transmission is preserved to a very satisfactory degree.

The carrier telephone channels are terminated in the long-distance switchboards in the usual way as, for example, at New York and Chicago for the Harrisburg-Chicago system described above; and connections

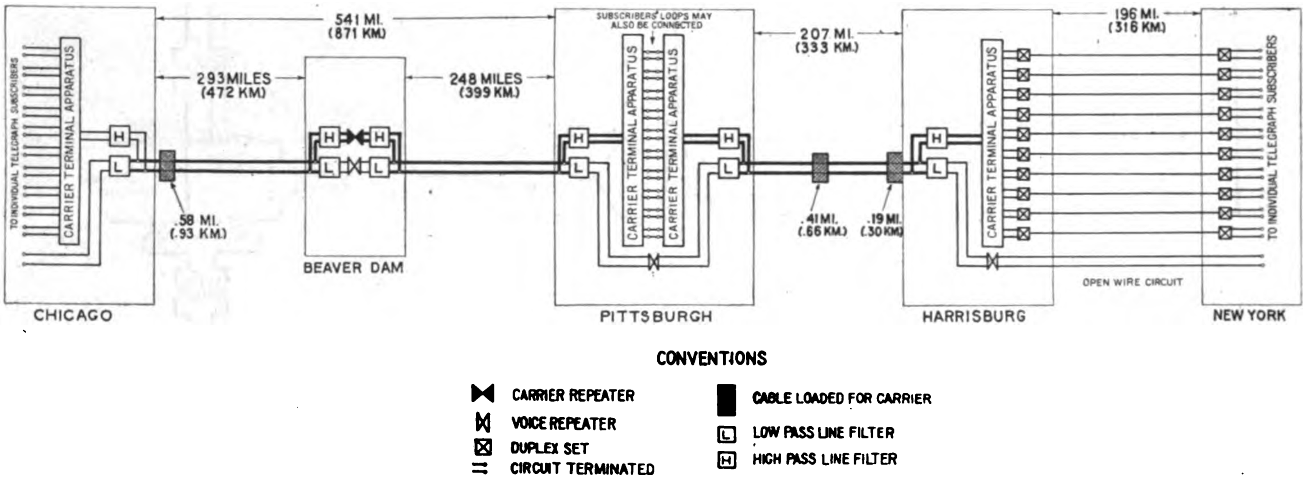

Fig. 58

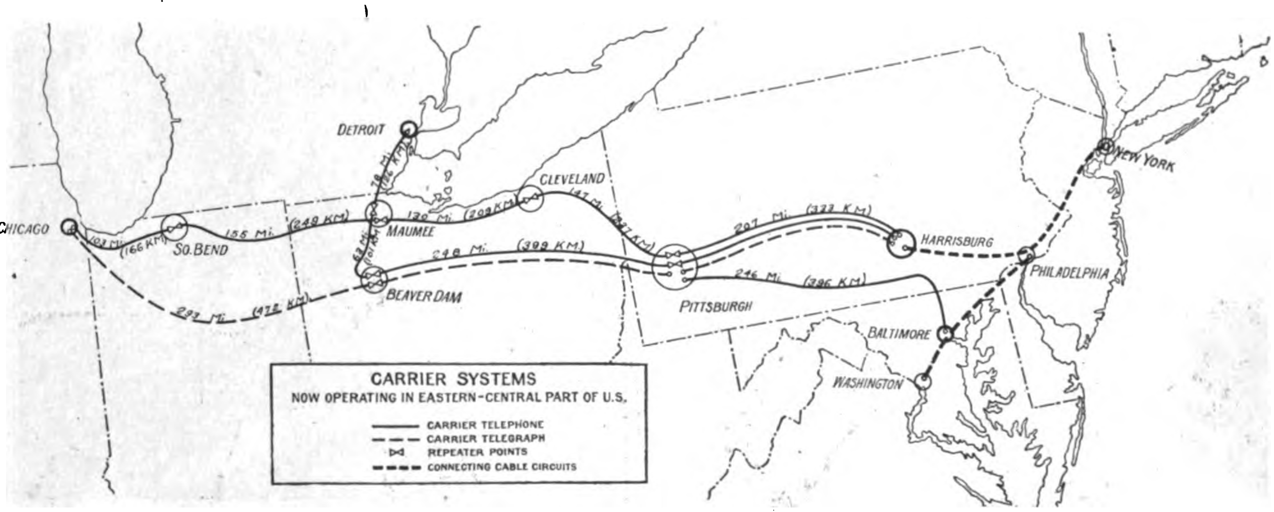

Fig. 59

are put up by the long-distance operators, using the regular toll cords. In fact, to the operators such circuits are indistinguishable from the regular long-distance repeatered circuits. The operator rings at the terminals of the connecting circuits in the standard manner, and the signals are automatically relayed over the carrier telephone channel as indicated in the circuit diagrams above, so that each carrier telephone channel is provided from end to end with its own signaling channel. The satisfactory working out of such operating features as these has been of much importance in completing the commercial usefulness of carrier telephone systems.

As has been indicated above the carrier telegraph systems as well as the carrier telephone systems, are designed to fit as an integral unit into a comprehensive wire plant, the relay-circuit arrangements providing for automatic repetition between the carrier channels and the connecting circuits, whether the latter be subscribers' loops or an additional section of long-distance circuit. The carrier telegraph circuits are used in the Bell plant, as are the regular composited Morse circuits, to furnish leased-wire service. The requirements for this service are particularly exacting as regards continuity and quality. The carrier telegraph circuits have proved to be very satisfactory in meeting these demands.

Reference was made in the first part of the paper to the fact that the carrier apparatus required for meeting the high standards of operation of a public service communication system is expensive. The technique involved in the art is so fascinating that one may readily lose sight of the more practical matter of costs, but to the engineer the economics of the situation are all-important, for it avails nothing if it is not possible to accomplish by the new method the same, or better, results than were obtainable with the old, at no greater cost. Carrier telephone systems—at least in the present state of the art—are economical in a general public service communication system only for use over relatively long distances. Of course, whether carrier can be justified in any given case depends upon factors peculiar to that case; in some instances, for example, it may not be physically possible to provide additional wires over a given toll line or cable route, in which case the relatively high apparatus costs may be easily justified. The carrier telegraph system is also essentially a long-distance proposition, although it is sometimes possible to warrant its use for distances somewhat shorter than in the case of telephone systems.

The authors wish to state that this paper is based largely upon the results of the engineering and research work of a great number of engineers on the staffs of Col. J. J. Carty, Vice-President of the American Telephone and Telegraph Company, and of Col. F. B. Jewett, Chief Engineer of the Western Electric Company. They desire particularly to acknowledge their obligations to Messrs. R. V. L. Hartley and Lloyd Espenschied, who, in addition to their very valuable contributions to the development of the art, have rendered special assistance to them in the work of preparing this paper.

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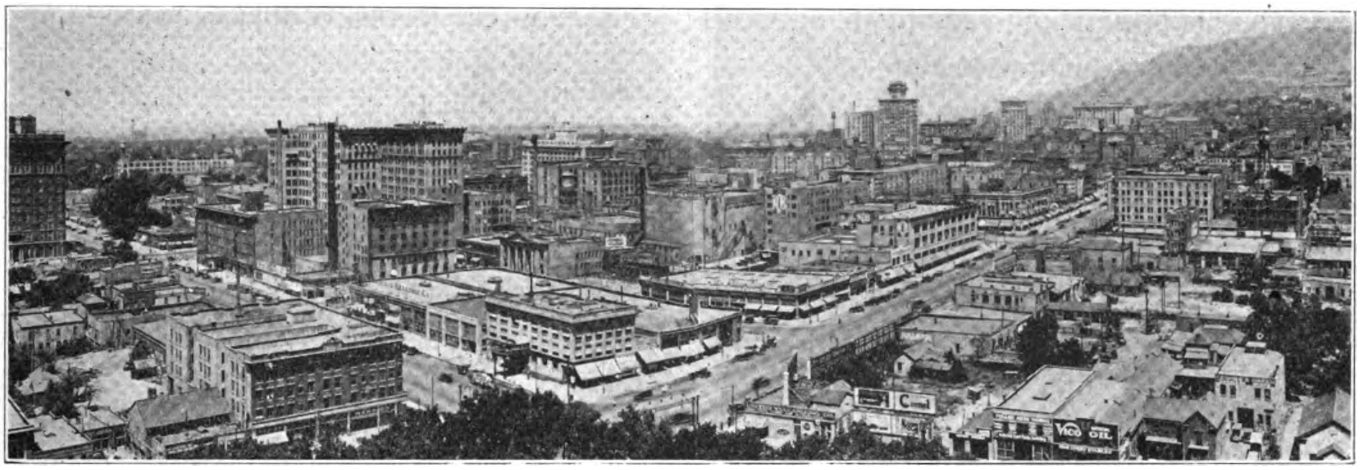
1919 TRANSACTIONS ERRATA

In the paper on "Problems of 220-Kv. Power Transmission," by A. E. Silver, published in Part 2 of the A. I. E. E. TRANSACTIONS, Vol. XXXVIII, 1919, Figs. 4, 5, and 6 on pages 1050, 1051, and 1052 each have one curve incorrectly drawn. These curves show transmission line characteristics. Correction slips are being prepared in the form of pasters, and will be sent on request to any one desiring to make these corrections.



SALT LAKE CITY FROM COUNTY BUILDING

Annual and Pacific Coast Convention

Salt Lake City, Utah, June 21-24, 1921

In the joint Thirty-seventh Annual and Tenth Pacific Coast Convention the Institute has provided an unusual opportunity to combine all the pleasures and benefits that are coincident with attendance at the yearly national meetings, with a trip to the center of scenic America. The Convention Committee and the Utah Section have arranged a program of technical sessions, excursions, dinners, lectures, recitals; tennis, golf and baseball; a program every detail of which has been so carefully mapped out, that arrangements to attend can be made with the full assurance that no effort has been spared to make this year's Convention a signal success.

Ladies are especially invited to attend and will find the afternoon and evening events of particular interest.

Institute headquarters will be located at the Hotel Utah and all technical sessions will be held there. Information Bureau and Registration Booth will be located on the mezzanine floor of the hotel.

An outline of the program follows:

Tuesday, June 21

The convention will open on Tuesday morning, June 21, 10.00 a.m. with an Address of Welcome by Charles R. Mabey, Governor of Utah, followed by the Annual Presidential Address by Arthur W. Berresford. A technical session will then take place. Directly succeeding the technical session, a luncheon for the Section Delegates is scheduled. This will serve as an opportunity for the delegates to become acquainted and to discuss points of interest to the Sections. Tuesday afternoon there will be a trip on foot past the most interesting, historical, Latter Day Saints buildings, followed by a short lecture and organ recital in the Tabernacle. At 7:00 p.m. an auto trip has been arranged to reach the famous Wasatch Boulevard at sunset and later to Capitol Hill. A return will be made to the Hotel Utah in time for an informal reception at 9:30 p.m., followed by dancing.

Wednesday, June 22

Wednesday morning, 9:30 a.m., the second technical session will be held. On Wednesday afternoon, a special train will leave from the Oregon Short Line depot at 12:30 p.m., over the Bingham and Garfield Railroad. Lunch will be served on the train. This trip, in addition to magnificent views of Great Salt Lake and Salt Lake Valley will provide an opportunity for Institute members to inspect a typical mining canyon. surface workings of the largest metal mine in the world with mills and smelters. On Wednesday evening there will be a meeting of the Section Delegates and Officers of the Institute, which will be open to all interested. A piano and harp lecture recital is scheduled for the evening at 8:30 p.m., Hotel Utah.—Mrs. Jacob A. Kahn, Pianist and Mrs. Marsh B. Boothby, Harpist.

Thursday, June 23

Thursday morning, beginning 9:30 a.m., will be devoted to the third technical session. The Board of Directors will meet at luncheon Thursday noon, and follow the luncheon with a short business meeting. For the forenoon, a special Entertainment for the ladies has also been scheduled, with a luncheon at the Literary Club. Thursday afternoon is assigned to an automobile trip to the Utah Power and Light Company's Terminal Station, the terminus of three 130,000-volt transmission lines, and said to be the largest outdoor substation in the world. Arrangements will also be made for those who wish to devote the time to golf or tennis. For the after-dinner entertainment, Dr. Broaddus will deliver an illustrated lecture on the wonderful canyons of Utah.

Friday, June 24

Friday morning, June 24, 9:30 a.m., is assigned for the presentation of various miscellaneous technical papers. On Friday afternoon, the finals of the Golf and Tennis Tournaments will be held. A baseball game between Eastern and Western members will start at 2:00 p.m. Bathing at Saltair Beach is scheduled from 5:00 p.m. to 7:00 p.m., followed by a Big Western Dinner in the Ship Cafe, with dancing for those who wish it.

Saturday, June 25

On Saturday, various *After Convention Trips* have been planned to local points of engineering interest, such as electric railways, power stations, pumping plants, smelters, mills, etc. Trips can also be made to Mountain Parks, Canyons, Brighton, Park City, and Bird Island, or to the Shoshone Falls, Bryce Canyon, Zion Canyon, the Grand Canyon and Yellowstone Park. For details see "After-Convention Trips and Excursions" below.

TENTATIVE PROGRAM OF TECHNICAL SESSIONS

Tuesday, June 21—10:00 A. M.

Welcome Address, by Charles R. Mabey, Governor of Utah.
President's Address, by Arthur Berresford.

Technical Committee Reports

Hydroelectric Developments at Niagara Falls, by J. L. Harper, and J. A. Johnson, both of Niagara Falls Power Company, Niagara Falls.

Modern Developments in Waterwheels, by W. M. White, Allis-Chalmers Co.

Wednesday, June 22—9:30 A. M.

Long Distance Transmission of Electric Energy, by L. E. Imlay. Superpower Survey, New York, N. Y.

Voltage and Power Factor Control of 66,000-Volt Transmission Lines Connecting Two Generating Stations, by Raymond Bailey, Philadelphia Electric Company.

Symposium on Long-Distance Transmission Systems.

a. *Voltage Regulation and Insulation for Large Power Long. Distance Transmission Systems,* by F. G. Baum, Consulting Hydroelectric Engineer, San Francisco, Cal.

b. *Some Transmission Line Tests,* by W. W. Lewis, General Electric Co., Schenectady, N. Y.

c. *Notes on the Operation of Large Interconnected Systems,* by L. L. Elden, Edison Electric Illuminating Co., Boston, Mass.

Modern Production of Suspension Insulators, by E. H. Fritz, Pittsburgh High-Voltage Insulator Co., and G. I. Gilchrest, Westinghouse Electric & Mfg. Company.

Thursday, June 23—9:30 A. M.

Voltage and Current Harmonics Caused by Corona, by F. W. Peek, Jr., General Electric Co., Pittsfield, Mass.

A Solution of the Porcelain Insulator Problem, by E. E. F. Creighton, General Electric Co., Schenectady, N. Y., and F. L. Hunt, Turners Falls Power & Electric Company.

Transformers for Interconnecting High-Voltage Systems or for Feeding Synchronous Condensors from a Tertiary Winding, by J. F. Peters and M. E. Skinner, both of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Electric Strength of Air Under Continuous Potentials and as Influenced by Temperature, by J. B. Whitehead and F. W. Lee, both of Johns Hopkins University, Baltimore, Md.

Friday, June 24—9:30 A. M.

Little Things from Little Places, by Guido Semenza, Local Honorary Secretary of A. I. E. E., for Italy; Consulting Engineer, Milan, Italy.

Synchronous Motors for Ship Propulsion, by E. S. Henningsen, General Electric Co., Schenectady, N. Y.

Magnetic Properties of Compressed Powdered Iron, by Buckner Speed and G. W. Elmen, both of the Western Electric Co., New York, N. Y.

Heat Losses in Conductors in A-C. Machines, by W. V. Lyon, Massachusetts Institute of Technology.

HOTEL RESERVATIONS

All members expecting to attend the convention should make their hotel reservations immediately. Address communications to Hotel Committee, A. I. E. E., 1212 Walker Bank Bldg., Salt Lake City, Utah.

HOTEL RATES, EUROPEAN PLAN

Hotel Name	Double Room One or Two People		Single Room One Person		Approximate Number Rooms
	With Bath	Running Water	With Bath	Running Water	With Bath
Utah	$8.00	$5, $6			
*Newhouse	$4, $5, $6	None	$3, $3.50, $4	None	100 All with bath
Kenyon	$3.50	$2, $2.50	$2.50	$1, $1.50, $2	40 to 50 rooms
New Grand	$3, $4, $5, $6	$2.00	$2, $2.50, $3	$1.50	30 rooms
Moxum	$4.00	$3.00	$3.00	$2.00	40 rooms
Semloh	$3, $3.50	$2.00	$2, $2.50	$1.25, $1.50	50 rooms
Wilson	$3.00	$1.50, $2	$2.50	$1, $1.50	30 rooms
Cullen	$3, $3.50	$2,$2.25,$2.50	$2, $2.50	$1.25, $1.50 $1.75, $2	25 to 30 rooms
Peery	$2.50,$3,$3.50	$2, $2.50	$2, $2.50	$1.50, $2	30 to 40 rooms

*Also 25 rooms with 2 single beds in each at $6.00.

TRANSPORTATION

It is important that members consult their local railroad agents and decide on the exact and most advantageous route to and from Salt Lake City for their purpose, and make their reservations as early as possible. Summer Excursion Rates take effect June 1st, offering round trip fares considerably below those now prevailing. These tickets permit stop-overs en route and are good until about October 31st.

Arrangements can be made to visit Yellowstone Park, the greatest scenic drawing card in the western United States, either enroute to or en route from the convention. The actual round trip fare via Yellowstone will not exceed that to Salt Lake City, and return, direct, the only additional expense being for transportation and accommodations in the Park. All expenses for the 4½ day trip through the Park amount to $45.00 via auto and camp route, and $54.00 via auto and hotel route.

As a very large number of eastern members will, of necessity, pass through Chicago, it is pointed out that the last train leaving Chicago in time to reach Salt Lake City for the first Convention session, Tuesday morning, June 21st, is train No. 19 over the Chicago and North Western R. R. and Union Pacific R. R. This train leaves Chicago 10:30 a. m., Sunday, June 19th, arriving in Salt Lake City at 8:20 a. m., Tuesday, June 21st. The round trip fare (summer excursion rates, all roads) from Chicago to Salt Lake City will be $77.76. Persons wishing to go over this route on the train mentioned above should communicate with E. E. Bogardus, City Agent, Chicago & Northwestern R. R., 148 S. Clark St., Chicago, Ill., and obtain their Pullman reservation; additional cars will be added to the train to meet the demand.

Those wishing to return via Kansas City or St. Louis can make the trip via the Denver & Rio Grande R. R. and the Missouri Pacific, passing through the magnificent Royal Gorge.

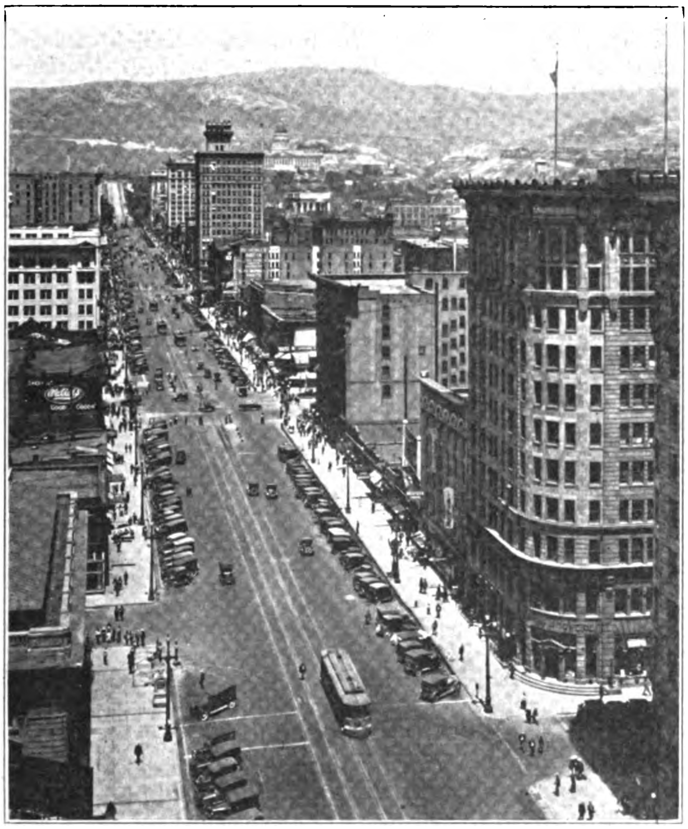
It is assumed that some members will wish to extend their trip to the Pacific Coast, and in that event should purchase Pacific Coast Summer Excursion tickets at their initial point, with stop over at Salt Lake City; similarly, members from the Pacific Coast may obtain summer excursion rates to points in the East with stop over at Salt Lake City.

SPORTS

Mershon Golf Cup. The Mershon Golf Cup will again be offered in competition. In the conditions of gift Past-President Mershon stipulated that to become the personal property of any member of the Institute he must twice win the golf tourna-

ment. So far, six golf enthusiasts have their names inscribed on the trophy.

John B. Fisken Cup. This cup, presented to John B. Fisken by the Portland Section, will also be competed for but by members of the Pacific Coast Section only. The winner of the golf tournament at which it will be offered will hold the cup only for the succeeding year.



BUSINESS DISTRICT, SALT LAKE CITY

In addition to the Golf and Tennis Tournaments and the Baseball Game between Eastern and Western members it will be possible for those members desiring to devote more attention to this feature to arrange for additional tennis or golf. The gymnasium of the Latter Day Saints immediately adjacent to the hotel will be available for the free use of members and will afford special bathing and exercise at any time of day.

LADIES ENTERTAINMENT

The Chairman of the Ladies Entertainment Committee has prepared a program which will provide a very wide range of entertainment. An effort will be made to have available at all times for those ladies who desire them, automobiles, guides to the Country Club, parks or canyons; tennis courts, gymnasium privileges; all kinds of bathing, sulphur water, fresh water, salt water. Six excellent bathing resorts including two hot springs are close to the city. Salt Lake City has many excellent stores and theatres. The wives of local members are planning to entertain the ladies with luncheons, theatre parties, drives, etc., during the time allotted to technical sessions. As a particular point of interest the committee calls attention to the fact that the National Federation of Womens Clubs will hold its annual convention in Salt Lake the week of June 12 to 16.

AFTER CONVENTION TRIPS AND EXCURSIONS

The following brief summaries give information regarding cost, method of transportation and time required for a number of trips which will interest engineers, both from the professional or educational standpoint and the scenic.

In the Rocky mountain country in which the Convention will be held, the electrical energy used is almost entirely developed by water power. Engineers interested in the production, transmission and distribution of power will have opportunity to see how it is done under very difficult topographical conditions. A number of the trips outlined show the application of hydroelectric power to the mining industry and how the problems of transmission are met.

A Bureau of Information will be maintained in the Hotel Utah where full information regarding any of the trips mentioned may be obtained and where visitors should register for such trips as they may desire to make.

Park City. The richest silver camp in the world and oldest in Utah. Elevation, 8000 to 11,500 feet. Located about 35 miles east of Salt Lake City on the Denver and Rio Grande Railroad, on transcontinental automobile route, an easy hour and a half drive from the city through beautiful Parley's Canyon. The largest electrolytic zinc plant in the west is located here. Representatives of the Utah Power and Light Company will welcome all visitors and conduct them on inspection. Reached by railroad or stage; fare approximately: $5.00. Time required: one day.

Eureka. Elevation, 6400 to 11,000 feet. Eureka is without doubt the most interesting metal mining camp in Utah. Produces copper, lead, zinc, silver, gold, iron and many of the rarer minerals. Shipments average fifteen million pounds of ore a week. Located about 75 miles due south of Salt Lake City on the Denver and Rio Grande or Salt Lake Route, or can be reached by automobile. Representatives of the Utah Power and Light Company will welcome all visitors and conduct them on inspection. Fare: railroad—approximately $9.00. Time required: two days. Fare: automobile—about $25.00 for the trip. Time required: one day.

Carbon County Coal Mines. 6,000,000 tons of high grade bituminous coal mined in this field in 1920. Interesting feature of this field is that instead of using steam electric power produced

SOUTH TEMPLE STREET, SALT LAKE CITY

from their own coal the mining Companies find it economical to purchase hydroelectric power for their mining operations. The mines are located 125 miles south of Salt Lake City and reached by the main line of the D. &. R. G. Ry. Railway fare, $13.74 round trip. Time about one and one-half days.

Mills and Smelters. If you are interested in seeing how ores are smelted and refined and have but a limited amount of time available, a short visit to either the United States Smelting Refining and Mining Company's smelter at Midvale, or the American Smelting and Refining Company's smelter at

Murray will be worth while. Both smelters can be reached by street cars which pass Convention headquarters. Cost of trip $2.00. Time required: one day.

Salduro—Potash Works. On the Great Salt Lake Desert, 100 miles west of Salt Lake City is a potash industry, a subsidiary of the Solvay Process Co. It is located on the main line of the Western Pacific Railroad and if you are going through to California over this road, you may be interested in stopping off one day to see it. It is a two day trip to see this industry and return to Salt Lake City. You will be taken care of over night at Salduro at nominal cost and can look over the process and return to Salt Lake City the next day. Total cost of trip, approximately $20.00.

Zion National Park, Cedar Breaks, Grand Canyon National Park and Bryce Canyon. A ten day scenic trip, magnificent in extent, has been arranged which takes in Zion

Bingham Copper Mines

National Park, Cedar Breaks, the North Rim of the Grand Canyon and Bryce Canyon, a new and unexplored country. If time is not available shorter trips can be made to any one or two of the above points of interest.

Round trip tickets for the popular "all Expense Tours," via National Park Transportation & Camping Company service, include all auto transportation and all meals and lodgings en route.

Zion and Grand Canyon Parks, Cedar Breaks and Bryce Canyon, 10 days, $140.00 per person.

Brighton Resort. (Big Cottonwood Canyon). One of the most inspiring touring trips to the heart and tops of the Wasatch range, southeast from Salt Lake City, is that to Brighton Resort, 36 miles from the city by automobile through Big Cottonwood Canyon. Here is a mountain locked retreat of striking and unusual beauty, one of the best for midsummer rest, recreation, and study. The altitude is 8600 feet. Accommodations at this charming Alpslike retreat are provided at the Brighton Hotel and the Balsam Inn, including lodgings and meals. The round trip fare from Salt Lake City will be $4.00 during the A. I. E. E. Convention.

MOUNTAIN CLIMBS

Those who feel the "Call of the Wild" will be able to satisfy it, for the Wasatch Mountains are almost at the door of the Hotel. All sorts of "climbs" and "hikes" are available, long cimbs, short ones and intermediate. If visitors will make their desires known at the Bureau of Information, full directions will be given and arrangements made for any kind of a climb or "hike" desired.

A. I. E. E. DIRECTORS MEETING
MAY 20, 1921.

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, May 20, 1921.

There were present: President A. W. Berresford, Milwaukee; Past-Presidents C. A. Adams, Calvert Townley, New York; Vice-Presidents Charles Robbins, Pittsburgh, L. T. Robinson, C. S. McDowell, Schenectady; Managers Walter A. Hall, Boston. Wm. A. Del Mar, W. I. Slichter, L. F. Morehouse, E. B. Craft, New York, G. Faccioli, Pittsfield, F. D. Newbury, Pittsburgh, Harold B. Smith, Worcester; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York. Present by invitation, William McClellan, of Philadelphia.

Approval by the Finance Committee of monthly bills amounting to $21,391.57 was ratified. The annual report of the auditors was presented.

Annual reports of the Board of Directors, the Treasurer, and of standing committees, were presented and accepted.

A report was presented of the Board of Examiners covering its meeting held May 13, 1921; and the actions taken on applications at that meeting were approved. Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 195 Students were ordered enrolled; 237 applicants were elected to the grade of Associate; 21 applicants were elected to the grade of Member; 19 applicants were transferred to the grade of Member.

The Meetings and Papers Committee reported upon plans in progress for the Annual and Pacific Coast Convention, at Salt Lake City, June 21-24, and presented a recommendation that the October meeting be devoted to the subject of lightning protection, under the auspices of the Protective Devices Committee, with the location of the meeting probably at Philadelphia. The Committee further reported that in connection with the joint meeting with the Society of Naval Architects and Marine Engineers to be held on the afternoon of November 17, 1921, a lecture will be given in the evening of the same day by Professor A. N. Goldsmith, on "World Communication." The report of the Committee was accepted.

Authority was granted for the organization of a Student Branch at Swarthmore College, Swarthmore, Pa.

The required procedure for amending the by-laws having been complied with, the Board voted to amend Section 44 of the by-laws to read as follows:

> Sec. 44. Reprints of any paper published by the Institute not exceeding 50 copies, will be furnished without covers, free of charge, for the personal use of the author if requested within thirty days after publication. Special covers will be charged for at cost.
>
> For reprints in excess of 50 copies, or when ordered later than specified above, a charge will be made.

The appointment of a Secretary for the year beginning August 1, 1921, was considered in accordance with Section 37 of the Constitution; Secretary F. L. Hutchinson was reappointed.

Upon the recommendation of the Chairman of the Committee on Economics of Electric Service, the Board voted to discontinue this committee at the close of the present administrative year, and directed that the necessary steps be taken to amend the by-laws accordingly.

Approval was given to the admission of the American Institute of Architects to membership in the American Engineering Standards Committee.

An invitation from the Society for the Promotion of Engineering Education, was accepted, to send a delegate to the annual meeting of that Society, June 28-July 1, 1921; and the President was authorized to appoint a delegate.

In addition to these actions many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the Journal under suitable headings.

JOURNAL
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A. W. BERRESFORD, *President*
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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

ANNUAL MEETING

ELECTION OF OFFICERS

The Annual Meeting of the A. I. E. E. was held in the Engineering Societies Building, New York, on Friday evening, May 20, 1921, President Arthur W. Berresford presiding.

The annual report of the Board of Directors was presented in abstract by Secretary Hutchinson. Pamphlet copies of this report had been printed in advance and are available to any member upon application to the Secretary of the Institute.

The report of the Committee of Tellers on the election of officers was then presented (printed elsewhere in this issue) and in accordance therewith, President Berresford announced the election of the following officers, whose terms will begin August 1, 1921: *President*, William McClellan, Philadelphia, Pa.; *Vice-Presidents*, Walter A. Hall, Boston, Mass.; N. W. Storer, Pittsburgh, Pa.; William A. Del Mar, Yonkers, N. Y.; C. G. Adsit, Atlanta, Ga.; John C. Parker, Ann Arbor, Mich.; F. W. Springer, Minneapolis, Minn.; H. W. Eales, St. Louis, Mo.; Robert Sibley, San Francisco, Cal.; O. B. Coldwell, Portland, Ore.; F. R. Ewart, Toronto, Ont.; *Managers*, A. G. Pierce, Pittsburgh, Pa.; R. B. Williamson, Milwaukee, Wis.; Harlan A. Pratt, New York, N. Y.; *Treasurer*, George A. Hamilton, Elizabeth, N. J.

The above, together with the following hold-over officers, will constitute the Board of Directors for the next administrative year: A. W. Berresford, Milwaukee, Wis.; Calvert Townley, New York, N. Y.; Walter I. Slichter, New York, N. Y.; G. Faccioli, Pittsfield, Mass.; Frank D. Newbury, Pittsburgh, Pa.; L. E. Imlay, New York, N. Y.; F. F. Fowle, Chicago, Ill.; L. F. Morehouse, New York, N. Y.; Harold B. Smith, Worcester, Mass.; James F. Lincoln, Cleveland, Ohio; E. B. Craft, New York, N. Y.

The wide geographical distribution of the Institute's Directors is indicated by the fact that thirteen states and Canada are represented in the above list.

REMARKS OF PRESIDENT-ELECT McCLELLAN

At the close of the business session President Berresford introduced President-Elect William McClellan, who spoke as follows:

It would be really a very strange man who would not be very happy, yes, and somewhat set-up at this time when such a very great honor is announced to him. After having worked along for a great many years with the men of an Institute like this, brother professional men, and then after these years to have been chosen to occupy this office of president, which has been held by so many prominent and worthy men, is about as great an honor as could come to any professional man.

At times like this I have sat in the audience and heard men say they had a feeling of humility, and all they asked for was to be able to do as well as their predecessors had done, and sometimes I might have slightly questioned their sincerity; but I assure you that tonight, when it comes to this position and I am faced with the responsibility of this very great office at the head of this wonderfully noble profession, there is a feeling of humility, and one does look at the work of his predecessors almost with awe, and wonders if by any possibility he can measure up to it.

But then right in the same moment comes a great feeling of buoyancy, especially just now, when we look forward and see what is to be done, because it is going to be a great year; and when we see and think of the great things that are facing the profession of engineering—and electrical engineering has certainly played its part among the leaders; when we look at the great movements taking place in which this profession is interested and concerned, they seem almost endless.

I have in mind that during the year, largely under the inspiration of one of our past-presidents, we have been able to get this new American Engineering Council working to take care of the interests of the profession, and to take care of the public welfare, so far as engineers can help in it. I see, through the leadership of that great engineer, Herbert Hoover, The Federated American Engineering Societies pointing the way to greater and greater work for the profession to accomplish, giving it a new vision, giving it a point of view which it never has had before.

Then, due to the war, I see opportunities for this profession, and they are many. Take the railroad situation, appalling as it is in this country today. Think of this great country with all its natural resources, with all its agricultural and mechanical and mining and manufacturing wealth. And then to see these great public utilities struggling, to see the great public not understanding their real function among us, that is, as facilities lying at the very basis of all our business. Without the railroads, without the power companies, without the electric railways, gas companies, telephone companies, water companies, and others, it would be utterly impossible in these times to conduct business, and as they are strong and able to function, so business will march forward, strongly and powerfully.

Then we are talking of reorganizing the government, and it is the purpose of engineers to play their part in connection with that. Further we have this great question of foreign trade, because we have passed in this country (and those engineers among you here that are connected with manufacturing plants know it), from the time when foreign trade was more or less of a luxury for a few people, to the time when it is the foundation of our prosperity. Someone has figured that the domestic demand in this country would not take over 70 per cent of the average of the productive capacity of the country, and if we worked to the potential productive capacity of the country, no one knows how much foreign trade and commerce we could supply.

We are not ready for it, and have not the facilities. One of the things we must do is to put a large number of foreign buyer

on their feet; for while we have magnificent national facilities for the buyer on his feet, we have none for those who are not on their feet. That work applies to the banker, but there is a side of engineering to it; as the bankers have said the risks are too great for them to sift out the weak from the strong, which is the work of the engineer, and no one can do it better than the engineer. We must turn our eyes to foreign trade and foreign commerce. It is our business; and we must assist in the formation of a great investment bank, that corresponds in foreign trade to what we call the investment banker in this country, in order to put that foreign buyer on his feet, so that he can buy from us and increase our prosperity and put our whole productive capacity to work.

Then you come back to the definition of what an engineer is—a man who can make one dollar do scientifically, according to engineering principles, what it would take $10.00 to do otherwise, and one man to do what it would ordinarily take ten men to do, etcetera. In this country of prosperity we must do things, and the engineer has a tremendous share in that great task, brought on partly by the war, more I think discovered by the war than brought on or caused by it, although one cannot deny our greatly increased productive capacity is largely due to it. Now, I say under these circumstances we need men. If engineers were called on today to solve this great immigration problem that seems to be worrying the country, I do not think they would turn back these immigrants, these able-bodied, fine, strong men and women, brought up to manhood and womanhood and ready to come here to work—they are worth a huge number of dollars to us. I think we would find some way of getting them into the country. We might establish ports of entry in the West, so that they could not stay here in New York; or if we selected them on the other side, that would be an engineering method; and then put them where they are needed, that would also be an engineering method; and the engineering genius of this country has to be applied to the problem before we can hope to succeed in having the prosperity we dream of. And as I look forward to the coming year, my only hope and prayer is that we all can play our part, small or great, as it may be, in this great task of rendering America prosperous.

LECTURE BY DR. ALBERT W. HULL

President Berresford then introduced Dr. Albert W. Hull, of the Research Department of the General Electric Co., who delivered a lecture on "The Magnetron—A New Electric Valve." The lecture was illustrated by numerous lantern slides and experimental demonstrations. It will be published in a future issue of the JOURNAL.

After a rising vote of thanks to Dr. Hull, the meeting adjourned.

REPORT OF COMMITTEE OF TELLERS ON ELECTION OF OFFICERS

To the President,
American Institute of Electrical Engineers.

DEAR SIR:

This committee has carefully canvassed the ballots cast for officers for the year 1921-1922. The result is as follows:

Total number of ballot envelopes received		4651
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 34, of the Constitution	50	
Rejected on account of voter being in arrears for dues on May 1, 1920, as provided in the Constitution and By-laws	99	
Rejected on account of ballot not being enclosed in inner envelope, or being improperly marked, or on account of inner envelope bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution	145	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution	19	313
Leaving as valid ballots		4338

These 4338 valid ballots were counted, and the result is shown as follows:

For President

William McClellan	3928
Charles S. Ruffner	261
Scattering	34
Blank	115

For Vice-Presidents

District		
No. 1. NORTH EASTERN—	W. A. Hall	4094
	Scattering	34
	Blank	210
No. 2. MIDDLE EASTERN—	N. W. Storer	3437
	J. B. Whitehead	636
	J. D. Lyon	48
	Scattering	34
	Blank	183
No. 3. NEW YORK CITY —	W. A. Del Mar	4051
	Scattering	34
	Blank	253
No. 4. SOUTHERN—	C. G. Adsit	3955
	Scattering	34
	Blank	349
No. 5. GREAT LAKES—	J. C. Parker	3280
	R. F. Schuchardt	849
	Scattering	34
	Blank	175
No. 6. NORTH CENTRAL—	F. W. Springer	4035
	Scattering	34
	Blank	269
No. 7. SOUTH WEST—	H. W. Eales	4027
	Scattering	34
	Blank	277
No. 8. PACIFIC—	Robert Sibley	4043
	Scattering	34
	Blank	261
No. 9. NORTH WEST—	O. B. Coldwell	4023
	Scattering	37
	Blank	278
No. 10. CANADA—	F. R. Ewart	3429
	Julian C. Smith	646
	Scattering	34
	Blank	229

For Managers

A. G. Pierce	3598
R. B. Williamson	3531
Harlan A. Pratt	2977
H. P. Liversidge	998
G. L. Knight	904
E. T. J. Brandon	451
Scattering	34
Blank	39

For Treasurer

George A. Hamilton	4064
Scattering	34
Blank	240

The scattering votes referred to in this report are shown in records of the committee deposited at Institute headquarters.

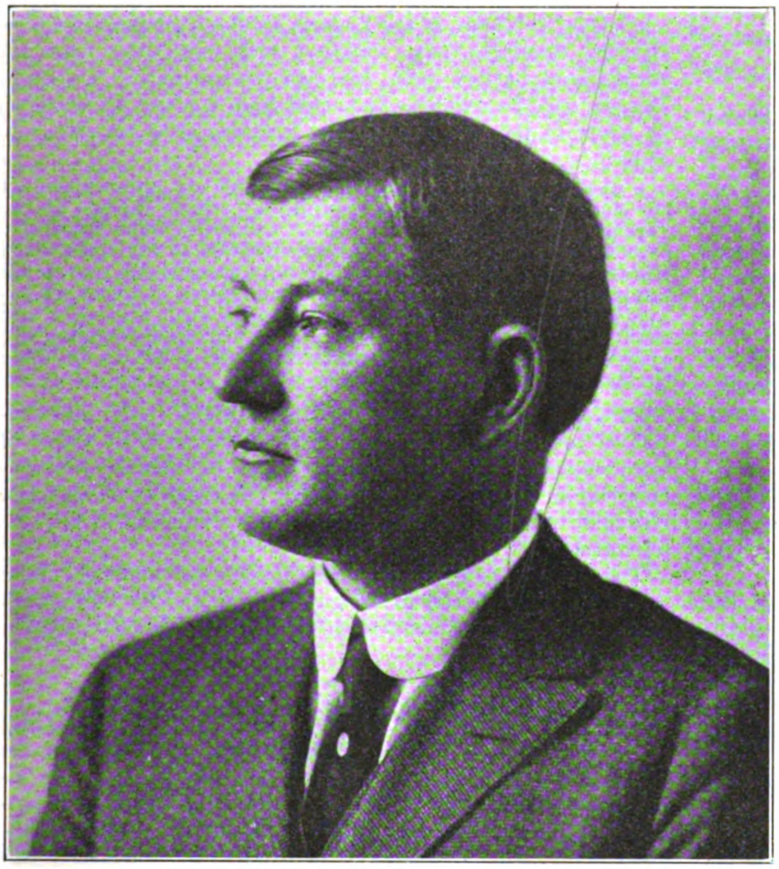
Respectfully submitted,
E. A. SKEHAN,
(*Signed*) JOHN D. POLLOCK
W. W. VERNON
CLYDE DRAKE,
WM. E. SEAMAN.

May 13, 1921. *Committee of Tellers.*

WILLIAM McCLELLAN
President Elect of A. I. E. E.

Dr. William McClellan has been elected President of the American Institute of Electrical Engineers for the year beginning August 1, 1921, as announced in the report of the annual meeting published elsewhere in this issue.

Mr. McClellan is a Philadelphia man by birth and education. He was graduated from the University of Pennsylvania in 1900 with the degree of B. S. and later with the degree of Ph. D., and in 1913 received the degree of E. E. After his graduation he was employed with the Philadelphia Rapid Transit Company engaged in all forms of railway and construction work, and became engineer in charge of construction. He left in 1905 to go to New York, with Westinghouse Church, Kerr and Company, and was later one of the managing engineers of this firm engaged in electrification and work on the railway terminals and tunnels. In 1907 he became associated with H. T. Campion of Philadelphia, in construction engineering, which association has been maintained to date, the present firm, McClellan and Campion, having offices in New York City and Philadelphia.



WILLIAM McCLELLAN
PRESIDENT ELECT A. I. E E

Mr. McClellan was for three years electrical engineer and Chief of the Division of Light, Heat, and Power of the Public Service Commission of New York State, Second District. Sometime after resigning from this work he organized and managed the rate investigation of the New York Telephone Company for the Commission.

Just before the war he was appointed Dean of the Wharton School of Finance and Commerce of the University of Pennsylvania, and remained there until 1919, when he became Vice-President of the Cleveland Electric Illuminating Company. During the war he was Director of the Intercollegiate Intelligence Bureau in Washington, an association of all the principal colleges of the United States to assist the government in obtaining trained men.

President-Elect McClellan has been active in Institute affairs. He first joined the Institute in 1904, was transferred to the grade of Member in 1909, and became a Fellow in 1912. He has been Manager and Vice-President of the Institute, and has served on various committees. He has also contributed valuable papers and discussions at meetings. He is a member of the American Society of Mechanical Engineers, of the American Society of International Law, the American Economic Association, the Academy of Political Science in the City of New York, the American Political Science Association, the Merchants' Association of New York, the American Gas Institute, and is at present a member and Chairman of the Finance Committee of the Executive Board of the American Engineering Council. His various society activities as well as his engineering experience well fit him to take up his duties as President of the American Institute of Electrical Engineers, and he brings to that office a broad vision and high ideals, coupled with executive ability, which will keep up the standards of the Institute.

BRADLEY STOUGHTON RESIGNS AS SECRETARY OF A. I. M. E.

Mr. Bradley Stoughton tendered his resignation as Secretary of the American Institute of Mining and Metallurgical Engineers, to the members of the Board of Directors of that Institute, on May 17, 1921. Mr. Stoughton expressed his reasons by his belief, as indicated to the president and some members of the Board two years ago, that the office of Secretary should not be a permanent one; but at that time he was persuaded to defer resignation until a more convenient time for the Institute. He feels that this time has now arrived. The Board of Directors accepted with regret Mr. Stoughton's resignation, expressing its appreciation of his long and efficient service to the Institute, and of the self-sacrifice with which he has devoted himself to the interests of the organization at the expense of his own professional choice or financial advantage. He became Secretary of the A. I. M. E. in 1912, and since that time the Institute has greatly increased in membership and in activities. Mr. Stoughton has offered to remain in his present office for a reasonable time, to assist his successor, when appointed, in familiarizing himself with the details of the work.

A. I. E. E. 1921 STANDARDS

A new edition of the Standards of the A. I. E. E. has been published and is now available for distribution. This edition which bears the date 1921 has been completely revised in form by the Standards Committee, under the direction of chairman L. T. Robinson, in order to correct some inherent defects in the form of the earlier editions, and to better adapt it to receive the additions which are made from time to time.

A number of changes in substance has been made and some new sections have been added in the new edition, which also contains the International Electrotechnical Commission rules for electrical machinery, adopted in 1919.

The book contains 172 pages 6 by 9 in., flexible cloth binding, price $2.00. (Discount of 25 per cent to Institute members.)

AMERICAN ENGINEERING COUNCIL

NATIONAL PUBLIC WORKS DEPARTMENT

American Engineering Council has announced that it would start a nationwide campaign for the establishment of a National Department of Public Works.

It will take over the entire machinery of the National Public Works Department Association, organized in Chicago in 1919 to bring about the reorganization of the Department of the Interior by the establishment of a National Department of Public Works. Senator Reed Smoot of Utah and Representative C. Frank Reavis of Nebraska, sponsors of the original public works legislation, are now leading in the movement for general government reorganization which, the engineers say, was largely inspired by the activity for public works reform.

Upon the recommendation of its Committee on Public Affairs, Council has officially determined that it will not concern itself with the general reorganization activities of the government, but will confine its efforts to the engineering and allied aspects of the Smoot-Reavis Committee program. This view, it was said, was shared by Herbert Hoover, who retired as president of Council. Adoption of a clear attitude on public questions was one of the last acts of Mr. Hoover's regime as head of Council.

At a meeting to be held in St. Louis on June 3, and which will be attended by engineers from many cities, Council will consider an elaborate plan for renewing the public works campaign in every state. The old public works state organizations will work in harmony with American Engineering Council under the general direction of L. W. Wallace, executive secretary of Council.

FOREIGN RELATIONS COMMITTEE

American Engineering Council has organized a Foreign Relations Committee with L. B. Stillwell of New York as chairman. Discrimination against American patents in Europe, the Council announces, has ceased as a result of the passage of the Nolan Treaty Patent Bill on March 3. The Patents Committee of Council had previously reported that American inventors were at a great disadvantage in foreign countries because of the lack of proper legislation. Council urges the passage of pending patent legislation to increase salaries in the United States Patent Office which is being crippled by wholesale resignations. The Patent Office, it was said, faces disorganization if remedial legislation is not enacted at the present session.

VISITING MEMBER PRIVILEGES WITH FOREIGN ENGINEERING SOCIETIES

The attention of the membership of the Institute is again called to the fact that several years ago, namely, in 1912 during the administration of President Gano Dunn, arrangements were made with several of the foreign Engineering Societies, entitling visiting members of the American Institute of Electrical Engineers to the privileges of membership in the Societies concerned for a period of three months, and foreign members visiting the United States are accorded corresponding privileges of Institute membership for a like period.

The underlying purpose of the formulation of this plan was the promotion of closer relations between the Institute and foreign Electrical Engineering Societies.

The Societies with which this arrangement is at present in force are as follows:

Institution of Electrical Engineers (Great Britain)
Societe Francaise des Electriciens (France)
Associazione Elettrotecnica Italiana (Italy)
Koninklijk Instituut van Ingenieurs (Holland)
Association Suisse des Electriciens (Switzerland)
Denki Gakwai (Japan).

There has been prepared for the use of Institute members while abroad a form of certificate which will serve as credentials from the Institute to foreign Societies. Any Institute member in good standing intending to go abroad may obtain such certificates upon application to the Secretary of the Institute, a separate certificate being furnished for each foreign Society.

Prof. A. R. Nissar, of the Victoria Jubilee Technical Institute, Byculla, Bombay, India, obtained such certificates from Institute headquarters some time ago for use during a visit to Europe, and the following is quoted from a recent letter which he wrote to the Secretary of the Institute after his return to India:

> I also take the opportunity to express my appreciation of the courtesies extended to me during my trip to Europe by the various sister Institutions in those countries, more especially France and Switzerland, on the presentation of my credentials, without which it would have been impossible to secure the numerous visits to places of electrical interest. I had an enjoyable and most instructive trip through such courtesies and shall be greatly obliged to you if you will kindly express my appreciation through the columns of the A. I. E. E. JOURNAL to the various sister Institutions of Europe.

Foreign engineers visiting the United States, upon presentation of proper credentials, are often furnished with letters of introduction to Institute members and to officers of manufacturing and operating companies. The facilities at Institute Headquarters, including the Library, are also accorded to visiting members.

The visiting member privileges involve no expense, either to Institute members or to foreign members, and the advantages which they offer commend them to the favorable consideration of the membership.

ROCHESTER ENGINEERS MEET

The engineers of Rochester participated in a joint dinner on May fifth, at the Powers Hotel, in which the following societies took part: American Association of Engineers, American Institute of Electrical Engineers, American Legion—Engineers' Post, American Society of Mechanical Engineers, Rochester Engineering Society, Rochester Society of Architects, and Rochester Society of Technical Draftsmen. Calvert Townley of the A. I. E. E., and first vice-president of the Federated American Engineering Societies, was the principal speaker of the evening. In his talk Mr. Townley prescribed a cure for business depression, saying that we must stimulate world trade by restoring the foreign markets. Putting the present stagnation of industry and commerce as due to the breaking down of our export trade, he suggested as a remedy the buying up of the most promising of European industries by American capital, and their operat on under American management, providing work at food wages for European labor, so as to create general prosperity on the other side of the water and thus restore normal purchasing power. In the meantime, he pointed out, the securities of the industries taken over, could be converted through the banks into American securities, enabling the promoters, with good management, to make a profit at both ends of the line, and at the same t me performing a valuable service to the country by creating an adequate outlet for surplus American products.

Other speakers were: W. Roy McCanne, president of the Rochester Chamber of Commerce, and Charles C. Evans,

president of the Rochester Society of Architects, who were introduced by John A. Robertson, of the Eastman Kodak Company, as toastmaster. Entertainment was provided by John P. Day, comedian, and Jesse B. Millham, song leader.

PAGEANT OF PROGRESS EXPOSITION

CHICAGO, JULY 30 TO AUGUST 14

The Pageant of Progress Exposition, to be held on Chicago's $5,000,000 Municipal Pier, July 30th to August 14th, 1921, will present a panorama of industrial progress, promising to be one of the greatest exhibits in years. One of the features will be electricity shown in all its variety of applications, and visitors to the exposition will see for the first time a complete history of the development and use of electricity.

The exhibits are being planned to tell the story of electricity in a picturesque manner. One sub-section, consisting of a series of six booths, will be devoted to the miniature representation of electric transportation. On the floor space of this section there will be full sized electric vehicles. Directly above these exhibits will be a panoramic painting, one hundred and forty feet in length, showing some scenes along the right of way of the Elevated and North Shore Electric roads, with a tiny model train in constant operation along the pictured track. Above this painting with its miniature train, will be a second painting. This will have scenes taken from along the right of way of one of the transcontinental railroads which has been electrified in part. This painting, which will also be one hundred and forty feet in length, will show miniature power houses, waterfalls, and tunnels, and there will be several model electric trains which run along this route and through the tunnels, operating continuously.

The story of lighting will also be told in an interesting fashion, and several surprising exhibits will be shown to illustrate the remarkable changes which take place due to lighting effects. These exhibits have been developed as a result of many interesting laboratory experiments. The many features will be so all-inclusive that it will take a day to see just the electrical exhibit alone in its entirety.

AMERICAN ENGINEERING STANDARDS COMMITTEE

CONFERENCES ON STANDARDIZATION

In compliance with a joint request from the American Institute of Architects and the National Association of Electrical Contractors and Dealers, the American Engineering Standards Committee held a conference in New York, on May 10th, to which representatives of all interested national organizations were invited, for the purpose of adopting a program looking toward the establishment of national symbols for electrical equipment in buildings. It was decided to ask the American Institute of Electrical Engineers, the National Association of Electrical Contractors and Dealers, and the American Institute of Architects to become sponsors for a sectional committee to deal with this subject. It was brought out at the conference that electrical equipment for buildings on land and afloat should be considered the same, and this ruling was adopted. Thus electrical equipment for ships will be included with that for other buildings.

The Bureau of Standards and the Society of Automotive Engineers, which have agreed to act as joint sponsor for a Safety Code for Aeronautics, called a conference in Washington, D. C., on May 13th. Representatives of interested national organizations were invited, to consider the scope of the proposed code, the method of its development, and the make-up of the sectional committee to be organized. This committee is now being organized under the sponsorship of the Bureau of Standards and the Society of Automotive Engineers.

STANDARDS RECENTLY APPROVED

Standards recently approved by the American Engineering Standards Committee include the following:

Submitted by the American Society for Testing Materials as Tentative American Standards:

5-1921 Standard Method for Distillation of Bituminous Materials Suitable for Road Treatment.

6-1921 Standard Method for Sampling of Coal.

7-1921 Standard Test for Toughness of Rock.

The Committee has also approved as American Standard the following code submitted by the National Fire Protection Association:

8-1921 National Electrical Code.

PERSONAL MENTION

H. R. Noack of the Pacific States Electric Company has been elected vice-president of the company.

John P. Rockwood has changed his business address from 95 Liberty Street to 71-73 West Broadway, New York City.

Frank V. Burton has left the Bryant Electric Company, Bridgeport, Conn., and is now sales manager for Henry D. Sears, Boston.

Kay A. Christiansen has left the Federal Telegraph Co., Palo Alto, Cal., to locate with the Pacific Tel. & Tel. Co., San Francisco, Cal.

F. Hymans, who was with the Otis Elevator Company, is now located with the Vibration Specialty Company, 303 Harrison Bldg., Philadelphia.

John E. Kelly, formerly of Humboldt, Tenn., is now resident manager of the Honduras Henequen Co., Inc., at Tegucigalpa, Republic of Honduras.

Harry W. Motter, of George F. Motter's Sons, York, Pa., announces the removal of the firm's office and storeroom to 335 West Market Street.

H. W. Hough, formerly with the Daniel M. Leuhrs Co., Cleveland, Ohio, is now with the Cleveland Electric Illuminating Co. as research engineer.

P. H. Chase has severed his connection with the American Railways Company, Philadelphia, and is now with the Philadelphia Electric Company.

J. R. Cravath has recently become president of the Pioneer Electric Company, electrical engineers and contractors, of Richmond, Cal.

J. P. Fish, who was with Stone & Webster, Boston, will be Located in India, with The Angus Company, Ltd., No. 3, Clive Row, Calcutta, India.

Harold C. Smith, formerly with the Iowa Telephone Company, Des Moines, Iowa, is now with the N. W. Bell Telephone Company, Fargo, North Dakota.

Jerome Blaisdell has left the Commonwealth Electric Co., Summit, N. J., and is located with The Depew & Lancaster Light, Power & Conduit Co., Lancaster, N. Y.

Chas. C. Allen, formerly with Dwight P. Robinson & Co., Inc., New York, is in Dallas, Tex., with the W. C. Hedrick Construction Co. Mr. Allen is vice-president of the company.

J. Ludwig Hansen, formerly of St. Anthony, Idaho, has moved to Salt Lake City, where he has established an office as consulting electrical engineer, in the Utah Saving & Trust Building.

W. L. Laing has changed from the Shepard Electric Crane & Hoist Co., Montour Falls, N. Y., to the Champion Engineering Co., of Kenton, Ohio, where he is superintendent of service and erection.

Charles F. McLaughlin has resigned as manager, Service Engineering Department, Kentucky Actuarial Bureau, and is now special agent at Bellefontaine, Ohio, for the Continental Insurance Company.

David D. Gibson, Jr., formerly with Stone & Webster Corporation as a designer, is now located with the Y. M. C. A. Extension School of New York City as associate head of the Electrical Department.

Charles H. Keel, formerly of the General Electric Company and of the Curtiss Aeroplane Corporation, has opened an office at 15 Park Row, New York City, for the practise of patent and trade-mark laws.

F. F. Burroughs, with the Mutual Fire Prevention Bureau, formerly located at Oxford, Mich., announces the removal of the bureau to 230 East Ohio St., Chicago. Mr. Burroughs is one of the managers of the bureau.

C. H. Shepherd, formerly electrical engineer in charge for the Commissioners of Lincoln Park, Chicago, has entered private practise as a consulting engineer specializing in street-lighting and general power-system engineering.

George C. Dean, of Dean, Fairbank, Obrieght & Hirsch, announces the removal of the firm's offices to 15 Park Row Building, New York City, where the practise of patent, trade-mark and corporation law will be continued.

R. S. Daniels, for fifteen years with the Washington Water Power Company of Spokane, Washington, has left for Berkeley, Cal., to take a position as assistant to the chief engineer of the California-Oregon Power Company of San Francisco.

Edmund J. Henke is now president of the American Electric Fusion Corporation, Chicago, recently organized, manufacturers of electric welding apparatus. Mr. Henke has been engaged in this field for a number of years.

Charles H. MacDowell was elected president of the Western Society of Engineers at the election held May 4th. Mr. MacDowell is president of the Armour Fertilizer Works, and brings to this position a wide experience as an executive.

Hartley Rowe, manager of the Detroit office of Lockwood Greene & Co., Engineers, has been transferred to Boston, as district manager of the Boston office, succeeding Kenneth Moller who was recently elected into the firm of Lockwood, Greene & Co.

Frank Sawford, formerly chief engineer of the Taylor Engineering Company, Ltd., Vancouver, B. C., has opened an office at 609 Credit Foncier Building, Vancouver, as consulting and constructing mechanical and electrical engineer, specializing in industrial power plants.

George Smith has been made president and general manager of the Vim Electric Company, Inc., of New York City, specializing in electric power equipment. Mr. Smith was formerly associated with the General Electric Company for eighteen years altogether, ten years of which were spent at the Sprague Electric Works as commercial engineer, and as manager of motor and generator sales.

F. H. Wilkins, European general manager of the International Western Electric Company with headquarters in London, has been elected a vice-president of his company. Mr. Wilkins entered the employ of the Western Electric Company forty years ago, eventually becoming manager of its New York branch. In 1910 he went to Europe to look over foreign trade conditions and a year later was made European general manager of his company.

Ira Cushing is now associated with The Condit Electrical Mfg. Co., South Boston, Mass., as a sales specialist, paying particular attention to circuit breakers, switchboards, and switching arrangements. Mr. Cushing had been with the General Electric Co. for more than eighteen years up to last year, when he was sales-engineer representing the Three-E Co., in New England. He is at present secretary-treasurer of the Boston Section of the Institute.

William S. Lee, vice-president and chief engineer of the Southern Power Company, Charlotte, N. C., has been elected president of the Piedmont & Northern Railroad, to succeed the late Z. V. Taylor. Mr. Lee has been connected with engineering construction in the South for nearly twenty-seven years, and has been a leader in the electrification of industries there. He has been vice-president of the Piedmont & Northern Railroad, which takes power from the Southern Power Company's system.

M. O. Leighton has been appointed director of the south-eastern branch of the Engineering Business Exchange, New York City, with offices in the McLachlen Building, Washington, D. C. The exchange conducts the purchase and sale of engineering and technical business properties. Mr. Leighton was for the past three years active in the work of Engineering Council being chairman of the National Service Committee. A. C. Oliphant, who was also a member of the National Service Committee of Engineering Council, will be associated with Mr. Leighton in the exchange.

F. M. Feiker of New York, vice-president and chairman of the editorial board of the McGraw-Hill publications, has been appointed as personal assistant to Mr. Hoover, his duties to consist of organizing and developing those branches of the Department of Commerce which relate directly to commerce and industry. Mr. Feiker has actively aided Mr. Hoover along other lines, having been a central figure in the movement with Mr. Hoover and the heads of engineering societies to enlist engineers in the problems of public service which resulted in the formation of the Federated American Engineering Societies, from the presidency of which Mr. Hoover has just retired; and being of aid in the development of the plan for the elimination of waste in industry, which was undertaken at Mr. Hoover's suggestion. He is a graduate of the Worcester, Mass., Polytechnic Institute, class of 1904, and an electrical engineer by profession.

OBITUARY

JOEL E. ANDERSON, of Joliet, Ill., died on April 2, 1921, following an operation. Mr. Anderson was born in Joliet, January 11, 1892, and received his early education there, later entering the Armour Institute of Technology, from which he was graduated in 1917. He then continued work with the Sanitary District of Chicago at the hydroelectric plant at Lockport, where he had been engaged part of the time during his college course, until April, 1918, when he enlisted in the army to serve during the war. After the war he was employed by the Cline Electrical Manufacturing Company, Chicago, and remained with that company until his death. Mr. Anderson was an Associate of the INSTITUTE.

WILLIAM A. LYNN, of Vallejo, Cal., died at San Francisco, April 10, 1921. Mr. Lynn was born near Salinas, Cal., October 5, 1873, and was graduated from the College of Mechanics, University of California, in 1897. During the next year he had charge of the University of California electric light station, and then became an instructor of Electrical Engineering in the university, leaving in 1902 to take a position with the San Jose and Santa Clara railroad. In 1908 Mr. Lynn was appointed to the position of expert electrical aid at the U. S. government yard at Mare Island, which position he held at the time of his death. His service was largely that of a consulting engineer, and his advice in engineering matters was continually sought by his associates. Mr. Lynn made many friends, particularly among the younger men, to whom he offered his personal interest and advice. He had been an Associate of the INSTITUTE since 1899.

WILLARD L. CANDEE, one of the pioneers in the telephone field, died suddenly on April 24, 1921. Mr. Candee was born in Yonkers, N. Y., March 28, 1851, and became interested in the telephone when it was still a novelty. He did much toward making its use popular, a telephone line which he built in Brooklyn between his boarding house and his father's residence being one of the first in that city. His range of engineering experimental work included arc lighting, telegraphing from a moving train, and the protection of exposed wires. Mr. Candee was connected with several of the older electrical companies in New York, having helped to organize the Jablochkoff Electric Light Company and the Telephone Company of New York, both of which were later sold. In 1884 he organized with Mr. Charles A. Cheever the Okonite Company, Ltd., of which he served as president for a number of years. Mr. Candee was formerly Captain of Company D of the Twenty-third Regiment of the National Guard of New York State, and belonged to the Montauk Club, the Brooklyn Riding and Driving Club, the Lotos Club of New York, and was a prominent Freemason. He joined the INSTITUTE in 1904.

EDWARD BENNETT ROSA, chief physicist of the United States Bureau of Standards, died suddenly in his office on May 17th.

Dr. Rosa has done notable work in electrical research. He was born in Rogersville, New York, Oct. 4, 1861. After his graduation from Wesleyan University, Middletown, Conn., in 1886, he entered Johns Hopkins University, Baltimore, and received the degree of Doctor of Philosophy. After serving as an instructor at the University of Wisconsin and as Professor of Physics at Wesleyan he became chief physicist of the Bureau of Standards in 1901.

One of his first achievements was to develop the physical side of the respiration calorimeter with Professor W. O. Atwater at Wesleyan. This apparatus was of great value in the pioneer investigations of the value of foods.

With Dr. Dorsey as collaborator Dr. Rosa in 1907 began work on the determination of the ampere. With Dr. Grover he collected practically all the known formulas for computing induction. This collection is known throughout the world as a model.

Another achievement was to definitely establish the laws governing electrolytic corrosion, a problem of major importance to public utility companies operating underground gas and water pipes and electric railways.

In the World War Dr. Rosa developed a number of scientific instruments of great value to the American forces in France. Among these were a sound ranging device for locating big guns, the geophone for detecting mining operations, the development of aircraft radio apparatus and the improvement of radio direction finders by which enemy ships and aircraft could be located. Under his direction the Bureau of Standards has established what is perhaps the finest radio research laboratory in the country. Dr. Rosa also perfected devices to insure safety devices in industrial plants.

Dr. Rosa has served as a member of the Standards Committee of the American Institute of Electrical Engineers; and of the Committees on Papers, and Nomenclature and Standards, as chairman of the Research Committee and as a director of the Illuminating Engineering Society; and he has been a very active worker for the American Engineering Standards Committee. At the time of his death he was an official representative of the Illuminating Engineering Society on the Governing Board of the American Association for the Advancement of Science; a Fellow of the American Institute of Electrical Engineers; a member of the U. S. National Committee of the International Electrotechnical Commission; a member of the main Committee of American Engineering Standards Committee as a representative of the U. S. Department of Commerce and a member of the Executive Committee; chairman of the Rules Committee, and chairman of the National Safety Code Committee of the A. E. S. C. In addition to the organizations just named he was a member of the National Academy of Sciences, American Philosophical Society, American Association for the Advancement of Science, the American Physical Society, the Societe de Francaise de Physique, the Washington Academy of Sciences, the Philosophical Society of Washington, and was secretary of the International Committee on Electrical Units and Standards.

He has been the recipient of the Elliott Cresson medal of the Franklin Institute.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Leo Arany, Room 201 Parkway Bldg., Broad & Cherry Street, Philadelphia, Pa.

2.—Paul H. Butler, Pittsburgh Transformer Co, 30 Church St., New York, N. Y.

3.— DeLos De Tar, 411 East 15th Street, Kansas City, Mo.

4.—Harry Dowling, 425 South Street, Pottstown, Pa.

5.—George W. Huey, R. F. D. No. 5, Wilkinsburg, Pa.

6.—Ernest H. Pearson, Electric Machinery Co., Minneapolis, Minn.

7.—Basil B. Pilcher, 691 East 230th Street, New York, N. Y.

8.—Martin Tracy, Tunnel Camp, Britannia Mines, Howe Sound, B. C., Canada.

9.—Harry Wilson, c/o J. G. White Engg. Corp., Marcus Hook, Pa.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (APRIL 1-30, 1921.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ALUMINUM.

By George Mortimer. Lond. and N. Y., Sir Isaac Pitman Sons, Ltd. (Pitman's common commodities and industries.) 152 pp., illus., tables, 7 x 5 in., cloth $1.00.

This little book gives a clear description, suited to the needs of lay readers and business men, of the processes by which aluminum is made and of its uses in industry, particularly in automobile and aircraft construction, the chemical industry, electro and electrical engineering.

CHILTON TRACTOR INDEX. Vol. 4, No. 1, January 1921.

Phila., Chilton Co. 456 pp., illus., tables 10 x 7 in., paper. $2.00.

This semi-annual handbook is a reference book for those interested in tractors and farm power machinery. It includes a directory of manufacturers of tractors, specifications of those on the market, with illustrations of most of them, a directory of manufacturers of farm power machinery, electric plants, motor trucks, etc., and a list of makers of tractor parts and equipment. General articles and tables of data valuable to makers and users are also included.

THE ELECTRIC LAMP IN INDUSTRY.

By G. Arncliffe Percival. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd. (Pitman's coommodities and industries.) 112 pp., illus., 7 x 5 in., cloth. $1.00.

A brief non-technical account of the development of electric lamps, with descriptions of the types in use today and the methods of manufacture. Not intended as a technical treatise, but for those desiring a general knowledge of the subject.

THE ELECTRIFICATION OF RAILWAYS.

By H. F. Trewman. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1920. (Pitman's technical primer series.) 78 pp. diagrams, 7 x 4 in., boards, $1.00.

This little volume is an outcome of the discussion as to the advisability or otherwise of electrifying the railroads of Great Britain, a subject of general interest because of the necessity for relieving railway congestion and utilizing coal in the most economical manner. Without going into technical details covered in the books on electric traction, the author brings forward the commercial aspect of the matter and calls attention to some of the main questions to which attention must be paid. Sufficient electrical information is given to enable these points to be understood by readers who are not electricians.

ELEMENTS DE MECANIQUE A L'USAGE DES INGENIEURS: RESISTANCE DES MATERIAUX.

By Robert d'Adhemar. Paris, Gauthier-Villars et Cie, 1921. 185 pp., diagrams, 9 x 6 in., paper.

In writing this book the author has attempted an introduction to the theory of the resistance of materials, in which the hypotheses that have been adopted to simplify the subject in practise are set forth as briefly and simply as is possible.

FIRE TESTS OF BUILDING COLUMNS.

By Associated Factory Mutual Fire Insurance Companies, the National Board of Fire Underwriters, and the Bureau of Standards, jointly conducted at Underwriter's Laboratories in Chicago, 1917-19. 388 pp., illus., charts, tables, 9 x 6 in., cloth. $2.50.

This pamphlet presents the results of an investigation undertaken to ascertain the ultimate resistance against fire of protected and unprotected columns as used in the interior of buildings, and their resistance against impact and sudden cooling from hose streams when highly heated. The results of 91 fire and 15 fire and water tests are given, including tests of representative types of steel, cast iron, concrete-filled pipe and timber columns, protected and unprotected, and reinforced concrete columns. It is stated to be the most complete investigation ever made.

HERBERT HOOVER; THE MAN AND HIS WORK.

By Vernon Kellogg. N. Y. and Lond., D. Appleton & Co. 1920. 375 pp., port., 8 x 5 in., cloth. $2.00.

Dr. Kellogg's book is the attempt of an observer, associate and friend, to tell, simply and straightforwardly, the personal story of the man and his work up to the present. His boyhood, education, work in Australia, China and London are recounted briefly, and much space is given to his work for the relief of Belgium, as American food administrator and as American relief administrator. As appendixes are given four important addresses by Mr. Hoover.

HIGH-TENSION SWITCHGEAR.

By Henry E. Poole. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's Technical Primer Series.) 118 pp., illus., 7 x 4 in., boards. $1.00.

The book gives a brief, general account of the subject. The more important points in the design are considered, but highly technical details are omitted, the object being to present the fundamental principles in a practical manner, so that the volume will fill the need for a handy survey of the subject for those who have not time for elaborate treatises.

HUMAN ENGINEERING; A Study of the Management of Human Forces in Industry.

By Eugene Wera. N. Y. and Lond., A. Appleton & Co., 1921. 378 pp., 8 x 5 in., cloth. $3.50.

This volume is a contribution to the discussion of the relationship of labor, capital and society in the industrial development of the world. Neither the old nor the modern school of management has succeeded in removing labor unrest, owing, in the author's opinion, to the ignoring of labor as a social group and disregard of the social purpose of industry. To present the principle of stimulating labor as a whole toward production at large for social purposes is the object of the present work.

The author studies the evolution of the ideas governing industrial relations, interprets the essentials of present issues, presents certain democratic tendencies and develops a typical organization for class cooperation. Other sections analyze the different psychological associations of men involved in industry, discuss the principles of human engineering and outline their application.

THE INTERPRETATION OF RADIUM AND THE STRUCTURE OF THE ATOM.

By Frederick Soddy. Fourth edition, revised and enlarged N. Y., G. P. Putnam's Sons, 1920. 260 pp., plates, illus., 8 x 6 in., cloth. $3.75.

This book is intended as a presentation of the subject in non-technical language, which will bring the ideas involved and their bearing upon current thought within the reach of the lay reader. The present edition has been rewritten to correspond with present knowledge, and a second part has been added in which the later developments, particularly those that bear upon the problem of the constitution of the atom, are set forth in briefer and less elementary form.

JOHN DALTON.

By L. J. Neville-Polley. Lond., Society for Promoting Christian Knowledge; N. Y., The Macmillan Co., 1920. (Pioneers of progress.) 63 pp., port., 7 x 5 in., cloth. $.80.

This brief biography gives the essential facts concerning Dalton's life, but is chiefly devoted to his scientific labors and their influence on chemistry. These are described carefully with as much detail as is usually wanted.

MAINTENANCE OF WAY CYCLOPEDIA.

Compiled and edited by E. T. Howson, E. R. Lewis, K. E. Kellenberg, assisted by Homer Hughes. N. Y., Simons-Boardman Publishing Co., 1921. 860 pp., plates, illus., diagrams, 12 x 9 in., cloth. $15.00.

The aim of the editors of this volume has been to present, in the simplest terms and the most convenient grouping, information covering a wide variety of subjects, of interest to railroad employees, division officers in charge of maintenance, operating officers having supervision over maintenance, purchasing agents and manufacturers. To accomplish this they have selected that which is representative of the best in this field, set forth the standards approved by technical societies and described devices of proved value.

The text is divided into sections covering Track, Bridges, Buildings, Water Service, Signals, Wood Preservation, and General Subjects. The arrangements of each section is alphabetical and the treatment deals with classes of appliances rather than with individual devices. A catalog section gives detailed information on specific contrivances. The volume contains over 2500 illustrations.

MARINE AND STATIONARY ENGINES.

By A. H. Goldingham. Second edition, revised and enlarged. N. Y., Spon & Chamberlain; Lond., E. & F. N. Spon. 1921. 206+27 pp., illus., plates, tables, 8 x 5 in., cloth. $3.15.

This treatise is offered to designers and operators in need of concise, practical information on the various types and designs of Diesel engines. The book opens with a brief account of the theory of the engine. This is followed by a description of the details of construction, and discussions of indicator diagrams, of the advantages and disadvantages of Diesel engines, and of their operation and maintenance. These general topics are followed by descriptions and drawings of many types of engines, illustrated by drawings.

THE MATHEMATICAL THEORY OF ELECTRICITY AND MAGNETISM.

By J. H. Jeans. Fourth edition. Cambridge, University Press. 1920. 627 pp., 10 x 7 in., cloth. $8.00. (Gift of the Macmillan Co., N. Y.)

Contents:—Electrostatics and current electricity.—Magnetism.—Electromagnetism.—Relativity.

There is a certain well-defined range in electromagnetic theory, the author states, which every student of physics may be expected to have covered with more or less thoroughness before proceeding to the study of special branches or developments of the subject. The present book is intended to give the mathematical theory of this range of electromagnetism, together with the mathematical analysis required in its treatment. It is written for the student and for the physicist of limited mathematical attainments.

The main changes in the fourth edition consist in a rearrangement of the later chapters and the addition of a new chapter on the theory of relativity. This attempts to present the broad outlines of the theory in the simplest possible way, suitable for students who approach the subject for the first time, equipped with such knowledge of general electrical theory as can be gained from the rest of the book.

MUNICIPAL ACCOMPLISHMENT IN CITY PLANNING.

Edited by Theodora Kimball. Bost., National Conference on City Planning, 1920. 79 pp. 9 x 6 in., paper.

This pamphlet summarizes the answers to a questionary sent to about 125 American cities that have been interested in city planning. It forms a convenient record of what has been accomplished in this direction during recent years, and lists the specific reports that have been made for the different cities.

NOTES ON IRRIGATION, ROADS AND BUILDINGS AND ON THE WATER SUPPLY OF TOWNS.

By William Lumisden Strange. N. Y., E. P. Dutton & Co., 1921. 849 pp., plates, illus., 9 x 6 in., cloth. $18.00.

In this volume an engineer with thirty years' experience on public works, chiefly in the Indian Public Works Department, presents the results of his professional career for the benefit of younger members of the profession. The book does not deal with matters of design, formulas and similar material available in the usual treatises, but discusses general principles and constructive details.

Much the largest section of the book is devoted to irrigation, which is discussed in considerable detail. The other subjects, town water supplies, roads and buildings are treated briefly. The book refers especially to Eastern conditions, and is intended to aid engineers there, who are usually general practitioners, called upon to carry out many kinds of work.

RADIOTELEGRAPHISCHES PRAKTIKUM

By H. Rein. Dritte auflage, von K. Wirtz. Berlin, Julius Springer, 1921. 557 pp., illus., diagrams, 9 x 6 in., cloth. 120 M.

The needs of the engineer in charge of radiotelegraph and radiotelephone stations are considered in this volume on the technique of plant operation. The various machines and apparatus are described, and their erection, methods of operation and maintenance explained. Directions are given for the necessary measurements, and the derivation of the more important equations is given. The work has been considerably expanded in scope since the publication of the second edition in 1910.

THE TESTING OF MOTIVE-POWER ENGINES

By R. Royds. Second edition. Lond. and N. Y., Longmans, Green and Co., 1920. 392 pp., diagrams, tables, 9 x 6 in., cloth. $7.50.

This book is intended for students with an elementary knowledge of motive-power engineering, who desire information on the practical testing of motive-power engines. Special attention is given to the variable conditions under which a plant may operate and the necessity for systematic arrangements where a series of trials is contemplated.

This edition has been revised and modified to meet modern developments.

THERMODYNAMICS AND CHEMISTRY.

By F. H. Macdougall, N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 391 pp., tables, 9 x 6 in., cloth. $5.50.

This book is intended for the advanced student in chemistry, for whom the author has endeavored to write a book that, in addition to being accurate, logical and sufficiently rigorous, will furnish him with numerous examples of the application of principles of the science.

DIE WARMEVERLUSTE DURCH EBENE WANDE UNTER BESONDERER BERUCKSICHTIGUNG DES BAUWESENS.

By Karl Hencky. Munchen und Berlin, R. Oldenbourg, 1921. 124 pp., illus., tables, 10 x 7 in., paper. 26 M.

This work is based on extensive experiments on the heat conductivity of walls of the usual types and of the customary building materials, carried out at the Munich Technical High School. From the results of these and general laws of the conduction of heat, the author has formulated equations to be used in designing heating installation. The book is intended for architects and for engineers engaged in the design of heating plants as a practical aid in calculating the size of installation.

THE WELDING ENCYCLOPEDIA.

Compiled and edited by L. B. Mackenzie and H. S. Card. Welding Engineer Publishing Co., 1921. 224 pp., illus., 9 x 6 in., cloth. $5.00.

This book is a collection of information on oxyacetylene electric and thermite welding, arranged in concise alphabetical form for ready reference. The material has been largely selected from the files of the "Welding Engineer," and is practical rather than theoretical in character.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—April 26, 1921. Paper: "Automatic Industrial Control." Author: Mr. S. H. Oberschmidt, Sales Engineer, Cutler-Hammer Co. A series of slides illustrating the talk were shown. Attendance 26.

Atlanta.—April 28, 1921. Elec. & Gas Bldg. Business meeting; adoption of Constitution and By-laws. Attendance 18.

Baltimore.—March 18, 1921, Johns Hopkins University. Subject: "Engineering in Connection with Street Railway Problems." Speaker: Mr. Charles De Mott Emmons, President, United Railways & Electric Co., Baltimore. Attendance 110.

April 15, 1921. Johns Hopkins University. Subject: "The Problem of the Electric Motor Car." Speaker: Dr. Charles P. Steinmetz. Attendance 500.

Boston.—May 3, 1921. Engineer's Club, Boston. Subject: "Electric Propulsion of Ships." Speaker: Mr. B. P. Coulson, Jr., General Electric Company, Schenectady. Attendance 85.

Chicago.—March 28, Western Society of Engineers Rooms. The moving picture "Queen of the Waves" was shown, followed by presentation of a paper on "Electric Propulsion for the Merchant Marine" by Mr. Wilfred Sykes, of the Steel & Tube Company of America. Attendance 128.

April 25, 1921. Western Society of Engineers Rooms. Joint meeting of the Chicago Sections of the A. I. E. E., A. I. M. & M. E., Association of Iron and Steel Electrical Engineers and the Electrical Section of the Western Society of Engineers. Papers "Demand Factor of Coal Mining Loads" by Mr. Carl Lee, Peabody Coal Company, and "Power Distribution Systems for Coal Mines" by Mr. W. C. Adams, Allen & Garcia Company. The papers were illustrated with lantern slides, and a film prepared by the U. S. Bureau of Mines and the Peabody Coal Company entitled "Modern Coal Mining Methods" was shown. Attendance 210.

Cincinnati.—April 14, 1921, Assembly Hall, Union Gas & Electric Company. Professor A. M. Wilson, of the University of Cincinnati, explained the operation of and demonstrated the Oscillograph. Col. T. H. Schoepf, Vice-President of the Cincinnati Traction Company, gave an interesting talk on economic operation of the Cincinnati street cars, and showed by the installing of the kilowatt-hour meters how the motormen have materially reduced kilowatt consumption per car mile. Attendance 53.

Cleveland.—April 19, 1921. Cleveland Engineering Society Club Rooms. Mr. R. F. Strickland, of the Nela Park Laboratories, arranged a "Wireless Concert" for the evening. Difficulty was encountered with the apparatus, due to both the receiving and sending apparatus being in high steel buildings. Attendance 248.

Connecticut.—April 22, 1921, Lawn Club, New Haven, Conn. Organization meeting. Adoption of By-laws; election of officers as follows: Chairman, Professor Charles F. Scott; Secretary-Treasurer, Mr. A. E. Knowlton; Executive Committee, Messrs. Samuel Ferguson, W. H. Bristol, W. C. Bryant, E. H. Everit and G. B. Leland. The Speaker of the evening was Dr. William McClellan of Philadelphia, who took as his topic the larger opportunities and obligations of the engineer and made an especial plea that the Section devote its thought to these broader aspects as well as to the details of engineering manufacture or operation. He expressed the wish that the Institute and the Section might indulge in more frank and open discussion of the baffling problems of the engineer. Reference was made to the aims and accomplishments of the recently formed Federated American Engineering Societies and to the fact that most of its work to date had been of the nature of unselfish public service rather than direct efforts to promote the advancement of the engineering profession. In concluding, Dr. McClellan urged that the fluid state of the world's business and political situation demanded that the citizen and engineer take counsel of courage and not of fear. Attendance 43.

Denver.—April 16, 1921. Kenmark Hotel. Subjects: "A Post Graduate Degree in Electric Traction, by a Steam Railroad Executive" by Mr. Ernest Stenger, of the Denver Tramway Company; "The Necessary Improvements in the Denver Water Systems" by W. F. R. Mills, Manager of the Water Commission of the Denver Water System. Attendance 30.

Detroit-Ann Arbor.—March 17, 1921. Subject: "Induction Motors." Speaker: Mr. Lane, Chief Engineer, Westinghouse Company. Attendance 250.

April 8, 1921. Subject: "Storage Batteries for Motor Power Service." Speaker: Mr. H. M. Beck.

Erie.—May 10, 1921, Academy High School Election of officers, for ensuing year as follows: Chairman, Mr. C. H. Schum; Secretary, Mr. P. B. Mansfield; Executive Committee, Messrs. H. Lamp, James Burke and H. Hansen. Subject: "Energy in its Relation to Modern Theory." Speaker: Dr. Charles P. Steinmetz. Dr. Steinmetz gave a popular exposition of the relativity theory, making use of several simple analogies, and avoiding all use of mathematics. Attendance 1385.

Fort Wayne.—April 21, 1921. G. E. Club Rooms. Subject: "Clocks and Watches, the History, Principles and Devices of Time-Keeping." Speaker: Mr. Chester I. Hall. After the talk the audience witnessed several interesting motion pictures including the manufacture of lead storage cells and the early discoveries relating to electricity. Light refreshments and smokes were provided by the Entertainment Committee. Attendance 40.

Indianapolis-Lafayette.—March 25, 1921, Chamber of Commerce, Ind. Subject: "Artificial Precious Stones." Speaker: Professor Frank B. Wade, Shortridge High School. Attendance 55.

April 29, 1921, Chamber of Commerce Building. Subjects: "The Effects of Low Power Factor Upon the Distribution of Electrical Energy and their Relation to Rate Schedules" by Professor C. Francis Harding, Purdue University; "The Determination of Power Factors in Polyphase Circuits" by Professor D. D. Ewing, Purdue University. Attendance 77.

Ithaca.—March 25, 1921, Franklin Hall, Cornell University. Papers: Abstracts were presented by various members of the School of Electrical Engineering of Cornell University as follows: "The Report on the Atlantic Super-Power Project," by Messrs. B. K. Shaner and H. A. Metzger; Lamme's "Story of the Induction Motor," Mr. R. C. Burt; "Automatic Stations and Substations," by G. C. Firket and C. Y. Yeh; "Flutter in Telephone Transmission," S. J. Cammataro. Attendance 23.

Kansas City.—April 29, 1921, University Club. Paper: ""Steam Turbines and Turbo-Generators." Author Mr. C. C. Douglas, of the General Electric Compay. The paper was illustrated by slides. Two reels of motion pictures entitled "Queen of the Waves" were also shown. Attendance 34.

Lehigh Valley.—May 5, 1921. Organization meeting. Adoption of By-laws; election of officers as follows: Chairman, Mr. L. C. Brooks; Secretary, Mr. H. G. Harvey. The meeting was held jointly with the Easton Educational Electrical Association. A moving picture furnished by the Westinghouse Elec. & Mfg. Co., entitled "A Romance of Rails and Power" was shown, followed by a most interesting and instructive talk by Dr. William McClellan on "The Broader Outlook of Engineering." The subject was dealt with in a broad manner

and appealed strongly for a more active interest in civic and political affairs on the part of engineers in general. Attendance 113.

Los Angeles.—April 22, 1921, Edison Hall. Subject: "Insulation of Extra High-Voltage Transmission Lines." Speaker: Professor Harris J. Ryan. (Illustrated by lantern slides). Mr. Harold Michener reviewed the history of the transmission insulator in Southern California leading up to the report of Mr. R. J. C. Wood on 220 kv. Insulator Studies. Mr. Wood gave a graphic description illustrated by numerous lantern slides of the studies made at Stanford University and in the Edison Laboratory on suspension insulator strings for 220 kv. lines. Attendance 140.

Milwaukee.—April 8, 1921. Local section Membership Committee gave a dinner at the Blatz Hotel in welcome to the newly elected members of the Section and applicants. Mr. A. W. Berresford, President of the A. I. E. E., was present and related in an interesting way incidents of his recent trip to England. He also covered briefly, for the benefit of the new members, the various phases of the activities of the A. I. E. E. and The Federated American Engineering Societies. Attendance 126.

April 20, 1921, Milwaukee Athletic Club. Subject: "The Social and Economic Status of the Engineering Profession." Speaker: Professor John C. Parker, University of Michigan. Professor Parker suggested that the standard of the engineering profession could be raised by increasing the college course to six years, and to include in the curriculum subjects which would prepare the engineer to take a more active part in the affairs of the nation. Attendance 200.

Minnesota.—March 28, 1921, Y. M. C. A. Subject: "Application of Electrical Energy to Industrial Processes." Speaker: Mr. V. A. Hain, General Electric Company, Chicago. The speaker enumerated the various uses to which electric ovens and furnaces are now being used, and pointed out the wide range of application to which this apparatus could be put today. He further gave the figures indicating the rapid growth and relative amounts of electrical energy used today in this class of industrial application. Attendance 22.

Philadelphia.—May 9, 1921, Drexel Institute. Subject: "Advantages of the Institute to Engineering Students". Speaker: Mr. H. P. Liversidge, The Philadelphia Electric Company. Films on various phases of the Electrical Industry were shown as follows: "Spiragraph," "Conquest of the Forest," "Revelations by X-Rays," "The Electrical Giant," "Forging Lines of Fellowship," "Making Telephones in Tokio." Attendance 204.

Pittsfield.—April 14, 1921, Park Club. Subject: "The Magnitude of the Stars." Speaker: Dr. Harlan T. Stetson, Professor of Astronomy, Harvard University, Cambridge, Mass. Attendance 125.

Portland.—March 22, 1921, University Club. Subject: "The Atlantic-Pacific Highways and Electrical Exposition." Speaker: Mr. John E. Gratke. A one-reel film entitled "The Electrical Giant" was also shown. Mr. Charles Austin, Radio Expert, gave a practical demonstration of wireless telephony and telegraphy which proved very interesting and instructive. Attendance 103.

April 22, 1921, Multnomah Hotel. In place of the regular meeting the Section joined in the Merchandising Conference" given by the General Electric and the Pacific States Electric Companies. As an added attraction, Mr. Robert Sibley made an address on "What Electrical Development means to Portland and the Columbia Basin." Attendance 50.

Providence.—May 3, 1921, Rooms of the Providence Engineering Society. Joint meeting with the Power Section of the Providence Engineering Society. Subject: "Bituminous Coal Stoker Practise." Speaker: Mr. F. C. Vandervort, Jr., of the Westinghouse Elec. & Mfg. Co. Attendance 40.

Rochester.—April 22, 1921. Mr. K. A. Hawley of the Locke Insulator Company, presented a discussion of the insulation of superpower lines. Mr. Hawley described the difficulties to be overcome in insulating the 220,000 volt lines soon to be put in service on the Pacific Coast. He described the results obtained in the laboratory by using graded strings of insulators and static shields to obtain better voltage distribution across long strings of suspension units. Attendance 48.

San Francisco.—March 24, 1921, Engineers' Club. Joint meeting with the American Society of Mechanical Engineers. Subject: "Efficiencies in Steam-Driven Power Plants." Speakers: Messrs. Robert Sibley and E. H. Delaney. Attendance 60.

Schenectady.—April 15, 1921, Edison Club Hall. Subject: "Illuminating Engineering." Speaker: Mr. W. D'A. Ryan, Director, Illuminating Engineering Laboratory of the General Electric Company. Colored slides were shown covering four main topics, historic lighting, from the early ages to the present, the Panama Pacific Exposition, modern street lighting and spectacular illumination. Attendance 210.

April 22, 1921, Edison Club Hall. Subject: "Engineering Organization." Speaker: Mr. A. W. Berresford, President of the A. I. E. E. Following an interesting discussion two motion picture films were shown, entitled "A Woolen Yarn" and "Our Daily Bread." Attendance 120.

May 6, 1921, Edison Club Hall. Subject: "The Origin and Energy of the Lightning Flash." Speaker: Dr. Charles P. Steinmetz. Dr. Steinmetz discussed the various phases of lightning explaining the theory thoroughly from beginning to end. All points were illustrated by pictures and explained by mathematical examples. Attendance 435.

Seattle.—April 19, 1921, Arctic Club Assembly. Subject: "The Introduction of the Automatic Telephone in Seattle." Speaker: Mr. D. J. Lundy. The speaker explained the operation of the new equipment and the procedure in connection with calls transferred from the automatic system to the manual. Diagrams and models were used in the explanation of the new system. Attendance 90.

Spokane.—April 15, 1921, Spokane Hotel. Dinner meeting. Subject: "Some Features of Early Electrical Developments in Spokane." Speaker: Mr. John B. Fisken. Attendance 38.

Syracuse.—March 10, 1921, Technology Club. Subject: "Recent Developments in Generators and Power Station Design." Speaker: Mr. F. D. Newbury, of the Westinghouse Elec. & Mfg. Co. Attendance 40.

April 15, 1921, Engineering College, Syracuse University. Subject: "The Oscillograph and Harmonic Analyzer." Speaker: Professor Charles W. Henderson. The address was accompanied by lantern slides showing oscillograms resulting from connecting various apparatus to circuits. Mr. Henderson also had a considerable amount of apparatus displayed for the inspection of those present. Attendance 47.

Toronto.—April 22, 1921, Toronto University. Subject: "The Cost of Power as influenced by the Present Economic Trend." Speaker: Mr. Paul M. Lincoln. The important points emphasized by the speaker were: In establishing energy charges, the quantity demand is fully as important as the integrated energy and often more so; demand should be measured, not estimated; power factor should be recognized in demand determination. Attendance 100.

Urbana.—April 15, 1921. Subject: "The Manufacture of Insulated Wires and Cables" (illustrated). Speaker: Mr. W. I. Middleton, of the Simplex Wire & Cable Co. Attendance 87.

Utah.—April 22, 1921, Commercial Club. Subjects: "The Manufacture of Leather Belting" by R. S. Nelson, of Charles A Schieren Company; "Electrical Developments in the West" by Mr. George E. Armstrong, Pacific Coast Editor, *Electrical World*. Attendance 35.

Washington.—April 12, 1921, Cosmos Club. Subject: "Storage Batteries, Their Characteristics and Applications"

(illustrated). Speaker: Mr. J. Lester Woodbridge, of the Electric Storage Battery Co. Attendance 181.

May 10, 1921, Cosmos Club Hall. Election of officers, for ensuing year, as follows: Chairman, Mr. A. R. Cheyney; Secretary, Mr. W. A. E. Doying; Executive Committee, Messrs. G. H. Ferry, Milton M. Flanders, Edward Kirschner, C. B. Mirick and R. P. Parrott. Two moving pictures entitled "Revelation" and "The Conquest of the Forest" were shown. Attendance 90.

PAST BRANCH MEETING

Alabama Polytechnic Institute.—May 5, 1921. Election of officers as follows: Chairman, V. C. McIlvaine; Secretary and Treasurer, J. M. Dickinson. Mr. V. C. McIlvaine delivered a talk on "Radio Operation and Engineering." Attendance 25.

University of Arkansas.—April 12, 1921. Subjects: "Should the Arkansas Corporation Commission Have Been Abolished" by Mr. S. Hollabaugh; "Some Facts about Centrifugal Pumps" by Mr. J. B. Rogerson. Attendance 11.

April 19, 1921. Subjects: "Automatic Control of Railway Substations" by Mr. L. C. Starbird; "Review of Industries in Europe" by Mr. Max Ware. Attendance 7.

Bucknell University.—April 20, 1921. Professor Hall gave Tesla Coil demonstration, also demonstrations with Geissler Tubes. Attendance 95.

Case School of Applied Science.—April 12, 1921. Subject: "The Industrial Application of Electrical Heating Appliances" (illustrated with slides). Speaker: Mr. R. A. Kaighen, of the Cleveland Illuminating Company. Attendance 38.

California Institute of Technology.—April 7, 1921. Mr. A. B. Allen of the Pasadena Municipal Light Plant gave practical demonstrations for action in electric shock or drowning accidents. Mr. O. C. Bulkley, a junior in electrical engineering gave a complete account of the changes in the National Electrical Code, and the inspection requirements for Pasadena installations. Attendance 17.

University of Cincinnati.—April 19,1921. Subject: "The Piping of Live Steam for Heating in Dayton, Ohio." Speaker: Mr. H. E. Deadorff, E. E. '22. Attendance 71.

April 26, 1921. Subject: "Maintenance of Electric Machinery." Speaker: Mr. M. S. Schneider, E. E. '22. Attendance 65.

May 3, 1921. Subject: "Electric Time Recording Devices." Speaker: Mr. Harlan Danner, E. E. '24. Attendance 40.

May 7, 1921. Annual stag. Professor A. M. Watson, toastmaster. Adresses by the following: Professor C. B. Hoffmann and Messrs. R. S. Redman, G. C. Browne, Andre Pingon, C. Doran, Francis Healey, and Dean Herman Schneider. Attendance 90.

May 10, 1921. Subject: "The 220-Kv. California Problem." Speaker: Mr. R. S. Redman. Attendance 57.

Clemson Agricultural College.—May 2, 1921. Subject: "From Falls to Factory." Speakers: Messrs. Abernathey and Spearmar. "Current Events by Mr. J. R. Rosa. Attendance 25.

University of Colorado.—April 21, 1921. Subject: "Construction and Operation of Power Transmission Lines" (illustrated). Speaker: Mr. Norman Reid, of the Colorado Power Company. Attendance 42.

Georgia School of Technology.—April 12, 1921. Subject: "The Relation of the Employer to the Technical Graduate." Speaker: Mr. W. R. Collier, Sales Engineer, Georgia Railway & Power Company. Attendance 26.

May 3, 1921. Joint meeting of local Branches of A. I. E. E. and A. S. M. E. The moving picture entitled "Queen of the Waves" was shown. Attendance 135.

Iowa State College.—April 20, 1921. The following films were shown: "Jupiter's Thunderbolts," "General Electric Company, Schenectady Works," "Big Deeds," "Romance of the Hardwoods" Attendance 78.

University of Iowa.—April 11, 1921. Subjects: "Selenium" by Mr. D. C. Shuttice, and "Mississippi Power Company" by Mr. F. Stohr. Attendance 33.

April 18, 1921. Subjects: "Seven Hundred Miles of Wire" by Mr. R. J. Tompkins, and "The Ohio" by Mr. E. Wilsey. Attendance 28.

April 23, 1921. Subjects: "Valuation" by Mr. R. L. Schacht, and "Future Wireless Telephony" by Mr. R. Wright. Attendance 26.

Kansas State College.—April 11, 1921. Election of officers as follows: Chairman, W. J. Bucklee; Vice-Chairman, L. E. Rossel; Corresponding Secretary Harold S. Nay; Recording Secretary, J. E. Beyer; Treasurer, G. L. Garloch; Marshall, M. C. Watkins. Attendance 38.

University of Kansas.—April 27, 1921. Election of officers as follows: Chairman, Erle S. Miner; Vice-Chairman, Henry Albach; Secretary-Treasurer, Clarence Harris. Subject: "Telephone Engineering." Speaker; Mr. C. J. Larsen, of the Kansas City Telephone Company. Attendance 30.

Lehigh University.—April 14, 1921. Papers: "Electric Furnaces" by Mr. E. F. DeTurk, E. E. '22, and "Departures from the Beaten Track" by Dr. Carl Hering. Attendance 73.

Michigan Agricultural College.—May 5, 1921. Chairman Fleming and Professor Sawyer talked on the advantages and possibilities of the A. I. E. E.; Mr. E. V. Sayles, a senior, explained some of the uses of the Terrill Regulator which he with several other seniors have obtained for the use of the department and are studying. Professor Cory gave a short talk on the opportunities of the electrical engineer. Refreshments were served. Attendance 70.

School of Engineering of Milwaukee.—April 22, 1921. Mr. C. E. Pettengill gave an interesting talk and demonstration of the "Headlight Laws" covering the following points: Demonstration of the various makes and types of lenses, discussion of the various state laws pertaining to automobile headlights, engineering problems which arise in connection with designing of the lenses and drawing up of the various state laws, actual demonstration of a pair of lenses on the street showing proper adjustment, etc. Attendance 58.

University of Missouri.—April 4, 1921. Election of officers as follows: Chairman, Professor A. C. Lanier; Vice-Chairman, R. P. Miller; Secretary, F. H. Miller; Assistant Secretary, B. C. Knerr; Corresponding Secretary, J. S. Palmer; Treasurer, E. J. McNeeley. Subject: "Use of Carrier Current in Telephony." Speaker: Mr. W. L. Blenden. The following moving pictures were also shown: "Romance of the Rails" and "King of the Rails." Attendance 35.

North Carolina State College.—March 15, 1921. Business meeting. Attendance 29.

March 23, 1921. Committees appointed for the electrical show. Attendance 25.

April 6, 1921. Time devoted to work on the exhibits for the electrical show. Attendance 25.

April 22, 23 and 25, 1921. Annual Electrical Show.

April 27, 1921. Election of officers as follows: Chairman, E. E. Inscoe; Vice-Chairman, H. S. Hill; Secretary-Treasurer, O. L. Bradshaw. Attendance 24.

University of North Carolina.—May 6, 1921. Subject: "Lighting from the Engineer's Viewpoint." Speaker: Professor P. H. Daggett. Attendance 35.

University of Notre Dame.—April 11, 1921. Subject: "Phenomena of the Induction Coil." Speaker: Mr. Ruzek. Attendance 18.

Ohio Northern University.—April 21, 1921. Subjects: "Resources of Niagara" by Mr. W. Janke, and "Romance of Invention" by Mr. D. Wolf. Attendance 14.

Ohio State University.—April 15, 1921. Subject: "Automobile Ignition." Speaker: Mr. J. H. Hunt, of the General Motors Research Corporation, Dayton, Ohio. Attendance 100.

Oregon State Agricultural College.—April 20, 1921. Discussion of the following papers "Development of Standardization" and "National and International Standardization." Attendance 20.

University of Pittsburgh.—April 12, 1921. The following papers were discussed: "The Amateur Wireless Station" by W. H. Raring, and "Electric Bonding & Coal Mining" by J. A. Connell. Attendance 30.

April 26, 1921. Subjects: "The Outlook of the Engineer for the Future" by C. W. Merritt; "Operation of the Power Plant at Jones and Laughlin Steel Mills" by R. P. Marshall; "Varying Currents" by W. H. Robinson. Attendance 29.

May 3, 1921. Subjects: "Wiring and Lighting Current Pertaining to Motion Picture Theatres" by W. L. Shutts; "Electroplating Industry in the U. S." by L. L. Hughes; "Loud Speaking Telephone Receivers" by J. O. Kleba. Attendance 31.

Purdue University.—February 22, 1921. The moving picture entitled "The Benefactor" was shown. Attendance 112.

March 22, 1921. Subject: "Business Letter Writing." Speaker: Dean A. A. Potter. The moving picture entitled "Big Deeds" was also shown. Attendance 69.

April 7, 1921. Subject: "Manufacture of Wire and Cable." Speaker: Mr. W. I. Middleton, of the Simplex Wire & Cable Co. Attendance 29.

April 26, 1921. Subject: "Electric Power Plants of Michigan." Speaker: Mr. H. J. Burton of the Consumers Power Company of Michigan. The film entitled "Revelations" was also shown. Attendance 87.

Rose Polytechnic Institute.—April 21, 1921. Subject: "Commercial Illuminating," illustrated with motion pictures. Speaker: Mr. J. T. McNarrow. Attendance 138.

Syracuse University.—April 22, 1921. Subject: "Electrification of Railroads." Speaker: Mr. George V. Round. Attendance 13.

University of Texas.—April 19, 1921. X-Ray Demonstrations by Dr. Dalton Richardson, of the Austin X-Ray Laboratory. Attendance 20.

Virginia Military Institute.—April 23, 1921. Subject: "Modern Refrigerating Plant." Speaker: Mr. Howard V. Shipley. Attendance 42.

Virginia Polytechnic Institute.—April 11, 1921. Subject: "The Theory of Sending and Receiving Messages by Wireless," illustrated by diagrams, and practical demonstration. Speaker: Mr. G. H. Poehlman. Attendance 18.

University of Virginia.—March 17, 1921. The following moving pictures were shown: "Queen of the Waves," "Land of Cotton," "The Potters Wheel," "Panama Canal." Attendance 46.

State College of Washington.—April 9, 1921. Joint meeting of local Branches of A. I. E. E. and A. S. M. E. Subject: "What a Student Should Get Out of his College Education." Speaker: Mr. H. L. Melvin. Attendance 80.

University of Washington.—April 14, 1921. Subject: "Recent Radio Developments." Speaker: Mr. J. Tolmie. Attendance 12.

West Virginia University.—April 25, 1921. Subjects: "The Colfax Power Plant" by C. M. Hill; "Electric Dredging on the Yukon" by H. Chandler; "Some Recent Developments in the Electrical Industry" by R. B. Walker. Attendance 16.

Yale University.—May 10, 1921. Subject: "The Birth and Babyhood of the Telephone" by Dr. Thomas A. Watson. A discussion of Dr. Watson's paper by Mr. J. T. Moran of the Southern New England Telephone Company. General short talk on the telephone by Messrs. Scott and Underhill. Attendance 205.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

LINEMEN AND LINE FOREMAN, first class. Location southeast. X-554.

ASSISTANT RESIDENT ENGINEER to supervise operation and maintenance of boilers, turbines and mechanical equipment of plant, reporting direct to Resident Engineer, who is in charge of entire installation. Must know how to direct proper burning of heavy Mexican crude oil in boiler plant. Must know how to make performance test on burners, boilers and turbines. Must know the keeping of complete and accurate plant operation data. Must be able to supervise the maintenance of plant equipment. Must have had at least five years' experience as operating engineer or superintendent in charge of steam and of large modern steam turbine plant, either commercial or industrial. Must be a graduate in mechanical or electrical engineering from one of the leading technical schools, such as M. I. T., Yale, Stevens, Pratt, Troy Polytechnic, etc. Spanish desirable but not essential. Age preferably about 35 years. Married or single, either. Both man, wife (if married) must be decent, high type, clean living people. Man must be good executive, good organizer, good handler of men and not a disturbing element. Three year contract. Location Chile. X-555.

INSTRUCTOR in Electrical Engineering in middle west state institution with 700 engineering students. Prefer a man with a little practical experience in addition to college course in line construction, house wiring or armature winding, although Instructor will not be expected to do any of this kind of work. Position for nine months, September 1st to June 1st. Location Middle West. X-556.

INSTRUCTOR who has an electrical engineering education and is qualified to teach general physics. After next year entire time would be devoted to engineering courses. For

the present would be expected to give one elementary course in a-c. and d-c. work with two lectures and one laboratory period each week; one advanced E. E. course of his own selection; one course in steam engineering and the balance of his time would be given to physics. Location South. X-532.

ELECTRICAL ENGINEER who understands small d-c. meter and generator winding; must have good experience with mechanical and executive ability, if not a worker do not apply; good salary to right man. First letter state full facts of past experience. Location South. X-533.

ENGINEER with fractional horse power motor experience. Location Ohio. X-535.

SALES ENGINEER acquainted with the application of electric motors to sell on commission basis d-c. power motors and either d-c. or a-c. grinders and polishers. Territory open—Boston, Pittsburgh, Cleveland, Cincinnati and St. Louis. Would not interfere with handling a non-competitive line selling to the same class of trade. X-542.

MECHANICAL UNIVERSITY GRADUATE for sales work with well established electrical manufacturers. Location Missouri. X-500.

CHIEF METER TESTER. Location Panama. X-507.

SALESMAN for company making electric fixtures. Sales experience essential. Interview 9-10. Commission basis. Location Greater New York City. X-510.

INSTRUCTOR for Electrical Engineering Department. Term beginning September. Send full information in first letter, and give three or more references. Location West. X-467.

ILLUMINATING ENGINEER for work on industrial lighting problems for contracting and electrical engineering firm. Man with wide industrial and some sales experience desired. One who would consider compensation on salary and commission basis preferred. Location Toronto, Canada. X-473.

ELECTRICAL ENGINEER. Prominent technical school has a permanent opening commencing September for a graduate engineer to take charge of electrical laboratory instruction. Experience of several years in electrical industry essential and one or two years' teaching experience desirable but not absolutely necessary. Location New York City. Excellent prospects for advancement. State fully education and experience; also age and religion; specify salary expected. Recent photograph desirable. X-476.

PROFESSOR OF ENGINEERING. Good ability, good appearance and one who is a good mixer. Preliminary work of the students is taken in college so that first year men are seniors or graduates. Second year men are graduates. Since the relations between students and instructors are very intimate it is necessary for cooperative organization work on the part of the instructors. Personality of the instructor is of great importance. Work will commence middle of July or September, preferably the former. After this year it will be from July 1 to May 1. Courses to be carried are Electricity and others according to experience of the man. Hydraulics and Heat and Power will probably be included. Application by letter. Location N. H. X-489.

TELEPHONE ENGINEERS capable of laying out a modern and up-to-date telephone exchange of central energy type in a town of about 15,000 population. Prefer a man with some little experience. Location Missouri. X-492.

SALES ENGINEERS with demonstrated selling ability to sell Elevator Guide Rail lubricator. Experience in building supply or power plant specialty lines desirable. Long residence in the city where they intend to work would be helpful. Men 25-35 would be most suitable. Territory open—Chicago, Philadelphia, Detroit and Cleveland. X-348.

SALESMAN to sell commutator stones in New York City and vicinity on commission basis. X-354.

INSTRUCTORS, two, in Electrical Engineering Department. Location Georgia. X-267.

MECHANICAL ENGINEER; Young man, single, for work in tropics, under direction of competent managing engineer, in enterprise established over thirty years. Prefer man having two or three years student courses in Westinghouse or General Electric. Work embraces simple building operations, road construction, operation steam and electric generating plants, drafting, designing plant changes and improvements and simple survey work. Three year contract. Liberal vacation allowance, free medical attendance, board and quarters. Excellent opportunity advancement if ability demonstrated. Submit full statement training, experience and character references. X-570.

MEN AVAILABLE

GRADUATE in law and electrical engineering; good knowledge of French and Russian; six years experience in U. S. and abroad; test floor, design and layout of switchboard, general engineering in turbine and turbo-generator work; familiar with estimating. Married. Desires position with consulting engineers or manufacturing concern; work along commercial lines considered E-2689.

PLANT AND CONSTRUCTION ENGINEER, age 33; technical graduate. Five years electrical construction, including power house, transmission line and substation. Four years mechanical and general plant construction. Two years steam plant operating and testing. Prefer position as plant engineer manager or assistant manager. Excellent references. Now employed; available on reasonable notice E-2690.

ELECTRICAL ENGINEER, experienced in design and construction of high and low-tension stations, also lighting and industrial layout work, desires to make change. Would consider position with engineering concern doing work of this character. Minimum salary $3000. E-2691.

ELECTRICAL ENGINEER, age 22; single. Graduate in June. Practical experience in contracting and construction. Commissioned in U. S. Engineers' O. R. C. Desires position with chance for advancement. Available July 1st. E-2692.

EXECUTIVE ENGINEER. Ten years electrical operation, construction and management, supervising engineer and industrial appraiser; two years Army, Captain Artillery; college graduate, age 32; married. In addition to technical and practical training, has a broad literary education, can write a clear concise letter, is strong on organization, and can fit in any where. E-2693.

ELECTRICAL ENGINEERING TEACHER desires change. Minimum salary $3500. Broad training and experienced along practical lines. Would consider either teaching or commercial work. Prefer teaching. E-2694.

ELECTRICAL ENGINEER, B. S., degree; age 25; single. Seven months experience with Westinghouse graduate student course. Desires position affording opportunity for advancement. E-2695.

TECHNICAL GRADUATE, age 31, desires position as electrical engineer or assistant with central station company, or as field engineer with consulting or constructing firm. Has had twelve years' broad experience in electric power plant, transmission and distribution design, construction, maintenance and operation. Available on short notice. Any location. E-2696.

ELECTRICAL ENGINEER, age 29; single. Two years G. E. test; two years G. E general engineering department on central stations. Associate A. I. E. E. Desires position with central station or construction company. Location Middle West. Good reference; available at once. E-2697.

GRADUATE ENGINEER, B. S. in E. E. 1920, age 25; married. Will receive degree of M. S in E. E. in June. Instructor in Physics Laboratory for three years. Have had experience in power house operation. Also experience in construction work. Interested in generation and distribution of electric power. E-2698.

MEMBER with twenty years experience covering shop supervision, invention, development and design of motor control apparatus and five years as chief of engineering department desires to make a change. Am seeking an executive position where past experience can be used and with prospect of advancement. Age 40; married. E-2699.

GRADUATE ELECTRICAL ENGINEER, age 30; desires sales or business connection. Considerable experience in sales correspondence. One years' experience in radio engineering. Also experienced in electrical testing. Preferred location; Wisconsin or vicinity of Chicago. At present employed, but available immediately. E-2700.

ELECTRICAL ENGINEER, age 34; with doctor's degree and of wide experience in development and design work, desires position in electrical enginering department of a university or research laboratory. E-2701.

TECHNICAL graduate; six years broad experience; design of industrial and power plants, chemical works, mining, special machines and apparatus. One position for three years as engineer and purchasing agent handling eight plants; each in a separate industry. Available immediately. Make offer. E-2702.

ELECTRICAL ENGINEER, married; fifteen years' experience in electrical and mechanical lines, including consulting and general construction work, design, installation and maintenance of industrial and commercial plant equipment, substations, overhead and underground distribution sys-

tems, etc. Desires position as plant electrical engineer or in consulting field. E-2703.

ELECTRICAL ENGINEER, age 23, graduating from college in June would like to become connected with an electric railway company or else one putting in steam and hydroelectric power plants. Has had some construction experience but would be willing to start from the bottom up with the right concern. E-2704.

ELECTRICAL ENGINEER having nine years' experience in design and operation of electric light power systems desires position with central station company or large engineering firm. Can handle men. Experience includes power station, substations, transmission, and a-c. and d-c. distribution overhead and underground. University graduate; married. E-2705.

ACTING DEAN AND PROFESSOR of electrical engineering in a State University was my last educational position. Attended Westinghouse Teachers' Conference and spent last years renewing practical experience. Member A. I. E. E.; A. A. E.; I. E. S. and S. P. E. E. Age 38; widowed; no family. Marked executive ability. Desires position of responsibility, in medium sized engineering school. E-2706.

MANAGER, SUPERINTENDENT, or executive electrical engineer. Technical graduate. Twenty-two years experience in steam and hydroelectric power plants, electric railways systems, high-tension transmission, low-tension distributing system and industrial layouts. Broad experience with public utility. Lately manager and engineer at hydroelectric power plant. Salary commensurate with position. Available immediately. E-2707.

ELECTRICAL ENGINEER, technical graduate; age 28; unmarried. Twenty months G. E. test, including turbines, motors, generators (a-c. and d-c.) regulators, transformers, panels, and calculation of test data. Experienced in industrial application of power and capable of making complete installations. Also technical correspondent. Available on short notice. References. E-2708.

SHRINKAGE ENGINEER. Industrial or public utility. Twelve years' experience electrical design, construction, inspection, maintenance and analysis work with electric power, street railway and telephone companies and U. S. Gov't. Technical graduate. Taking Alex. Hamilton Inst. Course. Seeking permanent position in New York or New Jersey or temporary anywhere. E-2709.

ELECTRICAL DESIGNER member A. I. E. E. age 35, married; Twelve years' experience in the design of power houses and substations and development of control apparatus. Desires position with concern in middle West with opportunity for advancement. E-2710.

ELECTRICAL ENGINEER with broad experience in power plant construction and operation for mining and handling of coal and ores; especially successful in handling labor. No objection to isolated location. Salary governed by location and opportunities. Served 3 years Major C. of E. U. S. A. E-2711.

CORNELL GRADUATE in electrical engineering, age 22; desires position with engineering, manufacturing or power company with opportunity for experience and advancement. Eight months' experience with Westinghouse. Available on short notice. E-2712.

PROFESSOR of electrical engineering; age 32. Five years experience as associate professor in leading technical colleges; also Westinghouse test course; engineer with large public utilities and consulting work. At present technical assistant to head of department of transmission of large public utility. Member A. I. E. E. and Illuminating Engineers. Text on electric power transmission in preparation. Desires position as head of department or professor in technical school of recognized standing, or as research engineer. Present salary $3600. E-2713.

ELECTRICAL ENGINEER, technical graduate. Five years General Electric Company. Two years on test. Sales experience. Specializes on motors. Electrician sergeant Coast Artillery during war. Wants connection where there is room for advancement. Age 22; Associate A. I. E. E. Available on short notice. E-2714.

CENTRAL STATION AND RAILWAY MANAGER and engineer. Technical graduate. Fifteen years' experience with large central station, railway, and lighting properties. Seeks position in executive or engineering capacity with central station, railway or industrial corporation, or engineering firm. Experience as sales engineer and on electrical construction. E-2715.

ELECTRICAL ENGINEER, age 27; married, three years' experience in testing and designing of electrical apparatus of all kinds, one year as an instructor in a mid-western University desires position with operating or construction company during the summer. Will also consider an instructorship during summer school. Member A. I. E. E., American Physical Society and American Mathematical Society. Best references. E-2716.

GRADUATE ELECTRICAL ENGINEER, age 29, married. At present in transportation department of large street railway company, wishes to make change. Five years experience electric street railway maintenance and operation; nine months sales engineering experience with well-known company manufacturing electric wires and cables. Desires permanent position in sales engineering with company manufacturing electric railway supplies or other electric machinery or devices. Would also consider permanent position in traffic analysis work or similar work allied to electric railway industry. New York City or Middle Atlantic States preferred. References furnished upon application. Available on two weeks notice. Mininum salary $3000. E-2717.

ELECTRICAL MECHANICAL ENGINEER, age 30; married. Member A. I. E. E. Four years' experience, electrification of steam railroads including layout and installation of apparatus and locomotive operation. Two years, Transportation Corps, U. S. Army, Asst. Supt. of Motive Power. One year in charge Experimental Dept. of large rubber tire company. E-2718.

RAILWAY ENGINEER. Extensive and varied experience in maintenance of both a-c. and single-phase equipment. Familiar with heavy traction electric locomotives and with multiple unit cars. Desires to connect with road serving growing territory in a responsible capacity. E-2719.

YOUNG MAN, age 24; married; wishes position where the following experience will prove of value. Three years underground transmission work; two years testing of motors and generators; one and a half years inspection and repair of electric controlling apparatus with some order department work. Graduate N. Y. E. S. and Assoc. Member A. I. E. E. Available immediately. New York City and vicinity preferred. E-2720.

ENERGETIC ELECTRICAL MECHANICAL ENGINEER desires position with public utility or industrial concern. Technical school and hard business education. American, age 38; wife and child. Eighteen years' experience in active management electric light, central steam heating, water works and telephone plants. Understands plant and commercial departments. Can handle public. Salary $5000. E-2721.

YOUNG ELECTRICAL ENGINEER, age 23, single. Technical education. Three years' experience in power plant and transmission work; four years' experience as mechanical and electrical designing draftsman. Desires position as an assisting engineer with a concern with good opportunity for advancement. Best of references. Associate A. I. E. E. Available immediately. E-2722.

GRADUATE ELECTRICAL ENGINEER, age 29. Two years General Electric Test. One and one-half years construction work; two years teaching in large university; one year in army. Would like to work for a large public utility in a place where he can study the management end of the game. Western location preferred. E-2723.

ELECTRICAL ENGINEER, age 32; married. Seven years' experience with large public service company. Five years in charge of construction as district superintendent. Familiar with line and cable construction. Also experience in manufacturing industry. Desire executive position. Salary $5000. E-2724.

ELECTRICAL MECHANICAL SUPERINTENDENT. Twelve years' experience in the design, construction, operation and maintenance of steam and hydroelectric generating stations, substations, low and high-tension transmission and distribution systems, Ex-Army officer (Major), broad experience in the handling of men; labor problems and work requiring executive and organizing ability. Member A. I. E. E. Age 34; available 15 days. E-2725.

TECHNICAL GRADUATE in electrical engineering; B. S. degree; member A. I. E. E.; age 24; single, wishes connection in engineering, manufacturing or light and power company, as construction engineer, affording opportunity for advancement. One years' experience. Location anywhere; available immediately. E-2726.

ELECTRICAL MECHANICAL TESTING ENGINEER, age 31; married; technical graduate. Six years' experience in operating, engineering and testing departments of the largest central station company in the middle West. Two years inspecting material at places of manufacture; two years chief inspector with large motor manufacturer. Associate A. I. E. E. E-2727.

PROFESSOR OF ELECTRICAL ENGINEERING, in one of our large universities for fifteen years desires to return to university

work in electrical engineering; has about finished the special research and development work that has occupied the past three years. A university interested in engineering research work is much preferred. E-2728.

Business Man. Position wanted on staff of financial, underwriting, or analytical organization to investigate commercial technical and scientific soundness of industrial, public utility and other business enterprises. Executive of broad business experience. E-2729.

Mechanical-Electrical Engineer, degrees B. S. and E. E. age 32; married. Experience gained in manufacture, sale, erection and operation of electric furnaces, and in management of electrometallurgical plants. Now with large corporation manufacturing products electrothermally, but seeks change and engagement with smaller organization, preferably one doing some research work. E-2730.

Graduate Engineer (E. E.) age 29; married; five years' experience with large public utility; two years with consulting engineers on appraisals, rate studies, cost work, distribution layouts, and estimating. Desires position with consulting engineers, public utility or manufacturing concern in Ohio or vicinity. E-2731.

Electrical Engineer, graduate M. I. T., married; with ten years experience in active, responsible positions on hydroelectric systems, desires position in West with public service company as engineer or executive; or in like capacity with consulting engineer; or with industrial concern. Experienced in management; meeting the public; sales; operation of plants; systems; apparatus; design and construction. Salary $4000. Reason for moving, desire to locate in West where most of experience was obtained. E-2732.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MAY 20, 1921

ABBOTT, GORDON A., Maintenance and Construction, Toronto Power Co.; res., 11 Charles St. East, Toronto, Ont., Can.

ABRAHAM, FREDERICK H., Technical Assistant, Bradford Corp., Electricity Dept., Town Hall, Bradford, Yorkshire, England.

ALEXANDER, HUGH GORDON, Power House Maintainence, City of Winnipeg Light & Power Dept., Point du Bois, Manitoba, Can.

ANDERSON, HERBERT M., Tester, Erie Works, General Electric Co., Erie, Pa.

ANGOVE, RAYMOND H., Editor, C-H. Messenger, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

ARMSTRONG, ROBERT B., Supt. of Construction, Wenatchee Valley Gas & Electric Co., Wenatchee, Wash.

ARMSTRONG, WALTER R., Asst. Chief Engineer, Oregon Short Line R. R. Co., 606 Desert News Bldg., Salt Lake City, Utah.

ATKINSON, WILLIAM H., Patent Attorney, General Electric Co., Commercial National Bank Bldg., Washington, D. C.

AVASTY, K. S., Engineer-in-charge (Substation), The Bombay Electric Supply & Tramways Co., Ltd.; res., 49, Kamathipura 5th Lane, Byculla Post, Bombay, India.

BECK, ROBERT C., Engineer, Cutler-Hammer Mfg. Co., New York; res., 37 Woodbine St., Brooklyn, N. Y.

BEGLEY, FRANCIS P., Chief Electrician, James B. Chow & Sons, Coshocton, Ohio.

BERRY, OLIVER F., Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 734 Franklin Ave., Wilkinsburg, Pa.

BLACK, JOHN, Foreman, Canadian Crocker-Wheeler Co., St. Catharines; res., 80 Huron St., Niagara Falls, Ont., Canada.

BLACKWEDEL, GEORGE H., Electrical Draftsman, with Thomas E. Murray, New York; res., 704 98th St., Woodhaven, N. Y.

BLERSCH, ROY E., Industrial Engineer, Century Electric Co., 506 Kirby Bldg., Cleveland, Ohio.

BLISS, MERVIN W., Instructor of Physics, Amherst College; res., 1 Woodside Ave., Amherst, Mass.

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BLUNT, WILLIAM J., Electrical Engineer, Spreydon Borough Council, Christchurch, N. Z.

BONZ, HENRY J., Installation Engineer, Choralcelo Company of America, Chicago; res., 2613 S. 59th Ave., Cicero, Ill.

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BOYCE, HARRY, Checker, Engineering Dept., Western Electric Co., 463 West St.; res., 156 E. 184th St., New York, N. Y.

BRADY, TERENCE M., Superintendent, Central Illinois Public Service Co., Effingham, Ill.

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BROWN, G. JAY, Chief Electrician, (Pitt River Development), Pacific Gas & Electric Co., Cassel, Calif.

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CALLENDER, DELMER W., Engineering Dept., Canadian Westinghouse Co., Hamilton, Canada.

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PLANT, GEORGE F., General Foreman, Trouble & Signal Div., The Milwaukee Electric Railway & Light Co., Milwaukee, Wis.

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RUISCH, EDWARD, Local Manager, Iowa Light, Heat & Power Co., Sanborn, Iowa.

RUSSELL, HENRY C., Apprentice, Electrical Handyman, Allis-Chalmers Mfg. Co.; res., 545 65th Ave., West Allis, Wis.

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WOLFF, BOYD L., Wolff Electric Works, 65 W. 9th St., Portland, Ore.

WOOD, EDWIN D., Electrical Operating Engineer, Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.

WOOD, LEWIS P., Electrical Engineer, Diehl Mfg. Co., Elizabeth, N. J.

WOOD, THOMAS B., Electrical Tester, B. F. Goodrich Co., Akron, Ohio.

WORTHAM, HENRY, Jr., Substation Operator, Public Utility Co.; res., 803 Lakeside Place, Chicago, Ill.

WORTMAN, JOSEPH C., Manager of Works, Novelty Incandescent Lamp Co., Erie Ave., St. Marys, Penn.

WORTMAN, RAYMOND B., Manager, Electrical Supply Shop, 31 Downer St., Baldwinsville, N. Y.

WRIGHT, M. M., Electrical Engineer, Christchurch Tramway; res., 12 Mayfield Ave., Christchurch, N. Z.

YANAGISAWA, YOSHIJIRO, Designing Engineer of Switchgears, Mitsubishi Zosen Kaisha, Kobe, Japan.

YOSHIO, TSUZUKI, Designing Engineer, Mitsui Miike Seisakusho, Omuta, Fukuokaken, Japan.

YOUNG, ARTHUR, Instructor, Federal Board, Vocational School, College of the City of New York; res., 501 Shepherd Ave., Brooklyn, N. Y.

YUNCK, WILLIAM K., W. K. Yunck Sales Co., 3149 Woodward Ave., Detroit, Mich.

Total 222.

*Former enrolled students.

ASSOCIATES REELECTED MAY 20, 1921

CHARLEY, REGINALD M., Engineer, Transformer Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 729 Sumner Ave., Pittsburgh, Pa.

COLE, JAMES L., Asst. Supt., Westinghouse Electric & Mfg. Co., Orange & Plane Sts., Newark, N. J.

COLLINS, WALTER F., Special Engineer, N. Y. C. R. R., Grand Central Terminal, New York; res., 514 Lafayette Ave., Brooklyn, N. Y.

FERGUSON, JOHN, General Supt., Indiana & Michigan Electric Co., 220 W.Colfax Ave., South Bend, Ind.

HECKSHER, SIGURD H., Supt., Electrical Engineering Dept., Pueblo Tramway, Light & Power Co., Pueblo, Pue., Mexico.

JEFFERY, JOHN J., Asst. Electrical Engineer, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont.

JERAULD, RODMAN E., Sales Engineer, General Electric Co.; res., 967 Second Ave., Salt Lake City, Utah.

JORDAN, FRANCIS J., Sales Engineer, Jarvis Electric Co., Ltd., 570 Richards St., Vancouver, B. C.

PARKER, THOMAS H., California Inspection Rating Bureau, 312 Balfour Bldg., San Francisco, Cal.

SCHMIDT, SIGURD H., Chief Draftsman & Plant Electrical Engineer, National Conduit & Cable Co., 163 Warburton Ave., Yonkers, N. Y.

STUART, LEMUEL M., Electrical Foreman, Ford Instrument Co., 80 Lafayette St., New York; res., 1448 E. 10th St., Brooklyn, N. Y.

TABER, RAY HOWARD, Electrical Instructor, San Diego High School, San Diego; res., 659 Del Mar Ave., Chula Vista, Cal.

THOMPSON, J. COX, Engineer, United Electric & Valley Railways Co., Lemoyne, Pa.

WARD, BALDWIN D., Consulting Electrical & Mechanical Engineer, 76 11th St., Oakland, Cal.

WEICKER, WILLIAM, Dr. of Engineering, Hermsdorf S.-A., Germany.

MEMBERS ELECTED MAY 20, 1921

AUSTIN, BASCUM O., Section Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 205 Franklin Ave., Wilkinsburg, Pa.

BATTYE, BASIL C., Engineer-in-charge, Sutlej River Hydro-Electric Project, Rupar, Ambala Dist.,Punjab, India.

BLACK, HOMER S., Asst. General Manager, Westinghouse Lamp Co., 165 Broadway, New York, N. Y.

CHERRY, TALMADGE C., Vice-President & General Manager, Rochester & Syracuse Railroad Co., 500 Syracuse Savings Bank Bldg., Syracuse, N. Y.

CHRISTENSEN, CHRISTEN, Chief Engineer, Electrical Engineers Equipment Co., 35 S. Desplaines St., Chicago, Ill.

CLARK, HAROLD M., Dist. Inspector, Electricity & Gas Inspection Service, 66 Victoria St., Toronto, Ont., Canada.

DAY, IRVIN W., Vice-President, The Connecticut Light & Power Co.; res., 12 1st Ave., Waterbury, Conn.

FORTIER, CHARLES L., Consulting Engineer, Johnson Service Co., 149 Michigan Ave., Milwaukee, Wis.

FUKUNAKA, SATARO, Chief Engineer, Nippon Electric Power Co., Imabashi, Osaka, Japan.

HAGELIN, BORIS C. W., Electrical Engineer, Standard Oil Co., Elizabeth, N. J.

HENTON, STUART C., Superintendent of Meters, Northern Ohio Traction & Lihgt Co., Terminal Bldg., Akron, Ohio.

HERD, PHILIP, Partner, Messrs, Rice, Wilson & Herd; res., Rock Ridge Road, Parktown, Johannesburg, S. Africa.

HILL, RAYMOND P., Manager of Maintenance, Crocker-McElwain Co.; Chemical Paper Mfg. Co., Holyoke, Mass.; res., 3410 Mountain Ave., El Paso, Texas.

KINTZING, R. TENCH, Control Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 828 Ramsey Ave., Wilkinsburg, Pa.

LAMBE, ALFRED B., Engineer, Dominion Power Board, Ottawa,nt O., Canada.

LEWIS, DU GUE K., Electrical Engineer, Winnipeg Electric Railway Co., Winnipeg, Man.

MANWARING, ROY A., Superitenndent, Dwight P. Robinson & Co., Seward, Pa.

RIDDICK, ARCHIE G., Electrical Engineer, Gulfport & Miss. Coast Traction Co., Gulfport, Miss.

SMITH, RODERICK N., District Engineer, Fred T. Ley & Co., Inc., Fairmount, W. Va.

SYLVESTER, J. WILSON, Supt., A C. & Arc Underground Lines, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

TODD, VICTOR H., Meter Test Engineer, Westinghouse Elec. & Mfg. Co., Newark; res., 427 Parkinson Terrace, Orange, N. J.

TRANSFERRED TO GRADE OF MEMBER MAY 20, 1921

AMOS, WALTER L., Electrical Engineer, Engineering Dept., Hydro-Electric Power Commission of Ontario, Toronto, Ont.

BEACH, ROBIN, Acting Head of Electrical Engineering Dept., Polytechnic Institute, Brooklyn, N. Y.

BOND, JOHN MILTON, Head of Car Equipment Test Dept., Interborough Rapid Transit Co., New York.

CORNELL, ROBERT L., Vice-President, Industrial Supply & Engineering Co., Lexington, Ky.

CRICHTON, LESLIE N., Section Engineer, Supply Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

DELLENBAUGH, FREDERICK S., Jr., Secretary, Research Division, Electrical Engineering Dept., Massachusetts Institute of Technology, Cambridge, Mass.

FAY, FRANK H., Supervisor, Printing Telegraph Service, American Telephone & Telegraph Co., New York, N. Y.

FLOOD, HENRY, JR., Engineer-Secretary, Superpower Survey, U. S. Geological Survey, New York.

GAYLORD, TRUMAN P., Acting Vice-President, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

GILLILAND, CLARENCE R., Manager, Railway & Power Depts., Westinghouse Elec. & Mfg. Co., Cincinnati, O.

HERR, EDWIN M., President, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HOFFMAN, A. J., Electrical Engineer, Lockwood Greene & Co., Chicago, Ill.

RYLANDER, JOHN L., Electrical Engineer, Motor Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

SHREEVE, HERBERT E., Telephone Engineer, Western Electric Co., New York, N. Y.

SPENCER, BURT K., Assistant Engineer with A. G. Wood, Philadelphia, Pa.

THURSTON, ERNEST B., Electrical Engineer, Haughton Elevator & Machine Co., Toledo, Ohio.

TOEPPEN, MANFRED K., Appraisal Engineer Michigan Public Utilities Commission, Detroit, Mich.

TRIPLETT, HUGH A., Electrical Construction Engineer, Midland, Pa.

WOOD, HENRY BLAKE, Electrical Engineer, Stone & Webster, Inc., Boston, Mass.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held May 13, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

MORELAND, EDWARD L., Partner & Manager, Jackson & Moreland, Boston, Mass.

WALLER, ALFRED E., Chief Engineer, Ward Leonard Electric Co., Mount Vernon, N. Y.

WEICHSEL, HANS, Chief Designing Engineer, Wagner Electric Co., St. Louis, Mo.

To Grade of Member

BINGHAM, ALBERT R., Superintendent, Canadian Light & Power Co., Montreal, Que.

CASE, RALPH E., Works Manager, John Johnson Co., Brooklyn, N. Y.

CLEGG, T. HERBERT, Assistant to Otto M. Rau, Philadelphia, Pa.

DANIELS, RAYMOND S., Electrical Engineer, Washington Water Power Co., Spokane, Wash.

DAVIS, ERNEST W., Asst. Electrical Engineer, Simplex Wire & Cable Co., Cambridge, Mass.

FIELD, FRANK E., Electrical Engineer, Western Electric Co., New York, N. Y.

FLEMING, DAVID B., Asst. Electrical Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

GEE, PAUL M., Foreman, Electric Drafting Division, Brooklyn Edison Co., Brooklyn, N. Y.

GERHARDT, CARL L., Electrical Engineer, United Verde Copper Co., Clarkdale, Ariz.

HARBAUGH, WILLIAM M., Engineer, Lehigh Portland Cement Co., Allentown, Pa.

HARTSHORNE, WILLIAM B., Service Engineer, Public Service Electric Co., Newark, N. J.

HILL, ARTHUR ST. J., Associate Professor of Electrical Engineering, University of Maine, Orono, Me.

JAMES, HAMILTON D., Manager, Industrial Division, Westinghouse Electric & Mfg. Co., Cincinnati, O.

JEFFERY, J. J., Asst. Electrical Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

KLAUDER, LOUIS T., Consulting Engineer, Philadelphia, Pa.

LYTHGOE, JOSEPH, City Electrical Engineer, Christchurch, New Zealand.

McAFEE, W. KEITH, Foreman, Sunnyside Engine House, Pennsylvania Railroad, New York, N. Y.

MALTHA, GERARD S., Chief Designing & Estimating Engineer, Ebro Irrigation & Power Co., Barcelona, Spain.

PALMER, HARRY R., Vice-President & General Manager, Harrisburg Light & Power Co., Harrisburg, Pa.

ROMANOVSKY, CHARLES, Commercial Engineer, General Electric Co., Schenectady, N. Y.

SCHIEFER, HENRY J., Jr., President & Treasurer, Schiefer Electric Co., Inc., Rochester, N. Y.

SCHWARTING, HARRY F., Assistant to Chief Electrical Engineer, American Car & Foundry Co., St. Louis, Mo.

STEVENSON, FRANCIS L., Chief Electrical Engineer, International Harvester Co., Chicago, Ill.

WYATT, FRANCIS D., Electrical Engineer, Union Gas & Electric Co., Cincinnati, O.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1921.

Acheson, Harry H., Bluefield, W. Va.
Adams, Charles H., Kenton, Ohio.
Adkerson, Branch O., Key West, Fla.
Ames, Chester E., Boston, Mass.
Anderson, O. W., Connellsville, Pa.
Angle, Wesley M., Rochester, N. Y.
Archer, E. G., Toronto, Ont.
Ayres, Lee T., Salt Lake City, Utah.
Back, John J., Waterbury, Conn.
Bahnson, G. Frederick R., Allentown, Pa.
Bindshedler, Theodore S., (Member), Philadelphia, Pa.
Bird, Jewett D., (Member), Waterbury, Conn.
Black, Donald C., Hyrum, Utah.
Black, Howard M., Toronto, Ont.
Blaisdell, Guy M., Boston, Mass.
Bockus, Gerald L., Sherbrooke, Que.
Booth, George G., Boston, Mass.
Brown, Darwin S., Cincinnati, Ohio.
Burke, John J., Boston, Mass.
Campbell, Archibald A. I., Boston, Mass.
Canfield, LaVergne D., New York, N. Y.
Casale, Anthony J., Takoma Park, Washington, D. C.
Ceccarini, Olindo O., (Member), New York, N. Y.
Clayton, Henry C., Boston, Mass.
Cottakis, Tassos M., Newark, N. J.
Cox, George H., Toledo, Ohio.
Crandall, Earl D., Lansing, Mich.
Cresswell, William A., Boston, Mass.
Cushing, Samuel T., Boston, Mass.
Davis, Maynard R., Salt Lake City, Utah.
Davis, Waldo F., Boston, Mass.
Day, Robert C., Salt Lake City, Utah.
Dealey, James, Winnipeg, Man.
DeWitt, Edward H., New York, N. Y.
Diehl, Edward M., Glendon, Easton, Pa.
Eilertsen, Henry R., New York, N. Y.
Emerson, Roger F., Schenectady, N. Y.
Emerton, Harry E., Boston, Mass.
Eyler, George A., Cumberland, Md.
Fear, S. Lorne, Toronto, Ont.
Flanigan, Andrew J., Cleveland, Ohio.
Focht, Albert W., Denver, Colo.
Garrison, Lloyd, (Member), Salt Lake City, Utah.
Gascoigen, Louis, Detroit, Mich.
Hage, David, New York, N. Y.
Hagen, Henry G., Boston, Mass.
Hagerman, George F., Boston, Mass.
Hale, Howard O., St. Louis, Mo.
Hall, George H., Boston, Mass.
Hall, Wesley B., New Haven, Conn.
Hamilton, Robert E., Toronto, Ont.
Hart, William A., Dawson, New Mexico.
Harvey, Harold F., Eldon, Mo.
Hastings, Norman H., Boston, Mass.
Heath, Ralph S., Salt Lake City, Utah.
Henderson, George, Toronto, Ont.
Hersh, George W., Erie, Pa.
Hicks, George E., Rico, Colo.
Hoffman, W. Hollis, Washington, D. C.
Howard, O. T., Atlanta, Ga.
Hunt, Edward J., Newark, N. J.
Ipsen, Carl L., Schenectady, N. Y.
Irick, Lewis W., Gibson, New Mex.
Jackson, Earle D., (Member), St. Paul, Minn.
Jarvis, Harold L., Boston, Mass.
Jeffery, Richard T., Toronto, Ont.
Jensen, Marion A., Omaha, Neb.
Johnston, George F., Milwaukee, Wis.
Jones, Alden C., Clarion, Iowa.
Jones, Clyde E., Boston, Mass.
Jones, Samuel W., Bingham Canyon, Utah.
Kaesemeyer, Charles F., Allentown, Pa.
Krueger, Harry H., Salt Lake City, Utah.
Kruse, Harry G., New York, N. Y.
Krusy, Gody, Newark, N. J.
Kurtz, Julius, Tooele, Utah.
Laws, Fred, Portland, Ore.
Lawton, James M., Turtle Creek, Pa.
Lloyd, William J., Denver, Colo.
Mandel, Aaron, St. Louis, Mo.
Marion, John F., Boston, Mass.
Maruyama, Junkichi, New York, N. Y.
Mason, Carl D., Argentine, Mich.
Melick, Martin L., Boston, Mass.
Moran, James F., Los Angeles, Cal.
Morita, Shigehiko, New York, N. Y.
Moulton, Albert B., Belmar, N. J.
Mueller, Charles A., Salt Lake City, Utah.
Muller, Frank J., Washington, D. C.
Mulholland, Clement B., St. Louis, Mo.
Murphy, John E., Boston, Mass.
Murphy, Walter, New York, N. Y.
McLellan, Herbert S., Boston, Mass.
Ochiai, Kaneyuki, New York, N. Y.
Pagel, Clarence J., Cleveland, Ohio.
Parks, Ralph S., Boston, Mass.
Perkins, Elliott R., Boston, Mass.
Perry, Charles T., (Member), St. George, S. I., N. Y.
Potts, Harold R., New York, N. Y.
Powers, Philip H., Logan, W. Va.
Ratta, James A., Boston, Mass.
Rauh, George J., Boston, Mass.
Richards, A[illegible]lay S., New York, N. Y.
Roadhouse, Wilbur Chicago, Ill.
Russell, Stanley A., New York, N. Y.
Ryan, Frederick C., Ft. Sheridan, Ill.
Schryver, Frank J., Dickinson, N. Dak.
Schwarz, Arnold E., Amboy, Minn.
Shaver, George W., Ogden, Utah.
Shaw, Ralph K., Boston, Mass.
Shoemaker, Herman, Newark, N. J.
Shore, William J., New York, N. Y.
Smith, Donald C., New York, N. Y.
Sorensen, August C., Detroit, Mich.
Sproul, S. M., Jr., Bangor, Pa.
Stewart, William A., Portland, Ore.
Tarbell, Raymond P., Cleveland, Ohio.
Tarr, Forrest E., Boston, Mass.
Taylor, Walter D. K., Boston, Mass.
Terven, Lewis A., E. Pittsburgh, Pa.
Thompson, Clarence V., Philadelphia, Pa.
Tripp, John P., Dixie Lachine, P. Q.
Vischer, Alfred, Jr., New York, N. Y.
Voronzoff, Paul I., New York, N. Y.
Wald, David, Brooklyn, N. Y.
Walsh, N. Steven, (Member), Montreal, Que.
Waltman, Charles B., Cleveland, Ohio.
Weld, Harold K., Chicago, Ill.
Welsman, Theodore S., Toronto, Ont.
West, James O., (Member), Elmira, N. Y.
Wharton, George E., St. Louis, Mo.
Wilson, Marion E., Atlanta, Ga.
Wood, Byron M., Boston, Mass.
Wygant, Walter H., New Haven, Conn.
Yarlett, Wilbur R., Pittsburgh, Pa.
Ziegler, Tobias F., Rock Springs, Wyoming.

Total 136.

Foreign

Ainsworth, Stuart, Arequipa, Peru, S. A.
Booth, John A., Rugby, Eng.
Gonsalez, Arturo, Jr., San Juan, P. R.
Gopalaiyengar, M., Mayavaram, S. India.
Komatsu, Mohachi, Kawasaki, Japan.
Lavarello, Juan J., Rancagua, Chile, S. A.
Mrojh, G. E., Kristiania, Norway.
McInnes, Edward H., Wellington, N. Z.
Reid, Irl C., Koko Head, Oahu, T. H.
Souja, Odilon E. A., Sao Paulo, Brazil.
Spencer, Thomas G., N. Woolwich, London, S. E., Eng.

Total 11.

STUDENTS ENROLLED MAY 20, 1921

13263 Walter, Thomas., School of Engineering of Milwaukee.
13264 DeVoe, Arthur A., Rensselaer Poly. Inst.
13265 Garbacz, George, School of Engineering of Milwaukee
13266 Beauman, L. Roy, University of Illinois
13267 Farnsworth, Hugh D., Ohio Northern Univ.
13268 Glick, Arthur A., Case School of Applied Science
13269 Le Blanc, Charles W., Carnegie Institute of Technology
13270 Menzel, Herman, New York Elec. School
13271 Blodgett, Randolph C., New Hampshire State College
13272 Cox, Newton, New Hampshire State Coll.
13273 Steed, Paul B., Carnegie Inst. of Tech.
13274 Myers, Roland B., Iowa State College
13275 Boboerg, Raymond W., Iowa State Coll.
13276 Wilson, Embree D., Iowa State College
13277 Henderson, F. Murray, Iowa State Coll.
13278 Lemen, Foster M., Iowa State College
13279 Ashton, Laston E., Toronto Central Technical School
13280 Mackay, William M., Toronto Central Technical School
13281 McMurray, James L., Union College
13282 Sheals, Vincent A., Union College
13283 Bricks, Harry M., Union College
13284 Brubaker, Orville K., Kansas State Agr. College
13285 Breslau, Harold, Johns Hopkins Univ.
13286 Muhlmeister, Albert A., Cooper Union
13287 Brown, Paul L., New York Elec. School
13288 Morton, Arthur S., School of Engineering of Milwaukee
13289 Martin, Clarence R., School of Engineering of Milwaukee
13290 Spaulding, George W., Mass. Inst. of Tech.
13291 Kovar, Paul, Kansas State Agr. College
13292 Reazin, George H., Kansas State Agr. Coll.
13293 Garman, F. R., University of Pittsburgh
13294 Freund, John J., Newark Technical School
13295 Hess, Charles W., Johns Hopkins Univ.
13296 Sittel, Virgil, Oklahoma A. & M. College
13297 Baughman, LeRoy B., Johns Hopkins University
13298 Koester, Henry F., Cooper Union
13299 Young, Howard E., Pratt Institute
13300 Watson, Dwight, Univ. of Washington
13301 Roos, Albert H., Univ. of Washington
13302 Borman, Ernest E., University of Wash.
13303 McKown, Paul M., Kansas State Agr. Col.
13304 Gibbs, Benj. F., Montana State College
13305 Fitzgerald, Edgar J., University of Kansas
13306 Hatheway, Donald H., Mass. Inst. of Tech.
13307 Peckham, Joseph W., Rhode Island State College
13308 Greene, Marcus C., Georgia School of Technology
13309 Husemeyer, William W., Montana State College
13310 Owenhouse, Manuel J., Univ. of California
13311 Riggs, R. A., Univ. of California
13312 King, Kenneth A., University of Southern California
13313 Fairchild, Charles V., University of Southern California
13314 Phegley, M. Melvin, University of Southern California
13315 Soo-Hoo, Peter, University of Southern California
13316 Albert, Edmond, Univ. of Southern Calif.
13317 Bailey, H. Morle, University of Southern California
13318 Willits, Ellis J., University of Southern California
13319 Walta, Joseph, Univ. of Southern Calif.
13320 Rowley, Robert E., University of Southern California
13321 Bailey, Gilbert S., University of Southern California

13322 Close, Gerald A., Pratt Institute
13323 Drews, William F., Lewis Institute
13324 Adams, Robert M., Stevens Inst. of Tech.
13325 Hasenpflug, University of Illinois
13326 Tomlin, Arthur R., Toronto Central Technical School
13327 Forster, Robert G., Toronto Central Technical School
13328 Hambrook, Richard E., California Institute of Technology
13329 Hart, Glen J., Montana State College
13330 Berg, William F., Jr., School of Engineering of Milwaukee
13331 King, Stuart N., School of Engineering of Milwaukee
13332 Kaplan, Aaron, City College of New York
13333 Brennan, Adam H., Pratt Institute
13334 Burt, Jairus F., Pratt Institute
13335 Carlin, Plato J., Pratt Institute
13336 Carroll, George W., Pratt Institute
13337 Charron, James, Pratt Institute
13338 Fellow, John E., Pratt Institute
13339 Gadbois, John S., Pratt Institute
13340 Ganung, Arthur E., Pratt Institute
13341 Hamill, Clifford H., Pratt Institute
13342 Hendrick, Douglas J., Pratt Institute
13343 Hicks, Howard H., Pratt Institute
13344 Hinman, George A., Pratt Institute
13345 Hoffman, Frank H., Pratt Institute
13346 Holcomb, Clifford E., Pratt Institute
13347 Holton, William G., Pratt Institute
13348 Hull, Clifford O., Pratt Institute
13349 Jensen, Louis M., Pratt Institute
13350 Jones, Russell B., Pratt Institute
13351 Kau, Philip F., Pratt Institute
13352 Kratz, Robert W. Pratt Institute
13353 Lee, Basil W., Pratt Institute
13354 Loomis, Clifford E., Pratt Institute
13355 Mansfield, Elwin C., Pratt Institute
13356 Marino, Gaspar, Pratt Institute
13357 Meldrim, Earl T., Pratt Institute
13358 Merwin, Kenneth G., Pratt Institute
13359 Murray, Elmer J., Pratt Institute
13360 McClennahen, Ross S., Pratt Institute
13361 McPherson, Robert, Pratt Institute
13362 Neufeld, Fred P., Pratt Institute
13363 O'Keefe, James J., Pratt Institute
13364 Paige, Harold C., Pratt Institute
13365 Pearson, Frank L., Pratt Institute
13366 Purdy, John H., Pratt Institute
13367 Putnam; George R., Pratt Institute
13368 Ralph, Albert H., Pratt Institute
13369 Redcay, Harold J., Pratt Institute
13370 Shoemaker, Horace, Pratt Institute
13371 Smith Edmund D., Pratt Institute
13372 Wallace, Dean N., Pratt Institute
13373 Warner, Robert W., Pratt Institute
13374 Webster, Francis P., Pratt Institute
13375 Weinstein, Harry, Pratt Institute
13376 Wetmore, Joseph E., Pratt Institute
13377 Wheatley, William B., Pratt Institute
13378 Williamson, Hugh R., Pratt Institute
13379 Woodward, Sterling C., Pratt Institute
13380 Zimmer, Cecil W., Pratt Institute
13381 Leary, John J., Pratt Institute
13382 Stose, Harold F., Mass. Inst. of Tech.
13383 Mickley, Earl B., Bucknell University
13384 Navarre, Thomas J., Michigan Agr. Coll.
13385 Thompson, Stewart M., Montana State College
13386 Browne, Walter I., Newark Tech. School
13387 Wilburn, John C., University of Nebr.
13388 Roser, Gerald B., Wentworth Institute
13389 Rauth, William R., Pratt Institute
13390 Robinson, Bernard C., Ohio Northern University
13391 Miller, George K., Alabama Poly. Inst.
13392 Dudley, James O., Worcester Poly. Inst.
13393 Crooks, Harlow, Ohio Northern University
13394 Korotzer, Nathan, Brooklyn Poly. Inst.
13395 Honig, Albert R., Jr., Mass. Inst. of Tech.
13396 Leonard, Jesse D., Westinghouse Technical Night School
13397 Seybold, Cleo R., Purdue University
13398 Campbell, Daniel A., Jr., Penn. State Coll.
13399 Garman, John C., Oregon Agri. College
13400 Argo, John P., Tri-State College of Engg.
13401 Kruger, G. P., Wentworth Institute
13402 Waller, Elwyn, Newark Technical School
13403 Wolf, David J., Ohio Northern Univ.
13404 Ratcliff, James H., University of Toronto
13405 Linhoff, Carl H., University of Minn.
13406 Mattern, George G., Penn. State College
13407 Hendricks, Chester I., Pratt Institute
13408 Lanier, William M., Jr., Univ. of Alabama
13409 Pringle, Arthur E., Penn. State College
13410 Cundall, Lincoln A., Worcester Poly. Inst.
13411 Fenstermacher, Walton S., Penn. State Coll.
13412 Johnson, Robert, Pratt Institute
13413 Tenney, Warren C., Pratt Institute
13414 Radlein, Ernest A., Pratt Institute
13415 Teders, Victor G., Johns Hopkins Univ.
13416 Davis, Frank L., University of Alabama
13417 Brance, Judd D., University of Alabama
13418 Tirrell, Reginald P., Wentworth Institute
13419 Brabb, Jerome M., Michigan Agr. College
13420 Shoemaker, George E., Jr., Mass. Institute of Technology
13421 Blasier, Herbert E., Jr., University of So. California
13422 Andrews, Miles J., University of So. Calif.
13423 Biggs, Leonard R., University of So. Calif.
13424 Engel, Anthony B., Georgia School of Tech.
13425 Dudley, Homer W., Penn. State College
13426 Bishop, Trenholme A. H., McGill Univ.
13427 Hatfield, Homer E., Rensselaer, Poly. Inst.
13428 Partridge, Kenneth L., Rensselaer Polytechnic Institute
13429 Black, LeRoy N., Rensselaer Poly. Inst.
13430 Fuller, Walter R., Rensselaer Poly. Inst.
13431 Mample, Wilford P., Rensselaer Polytechnic Institute
13432 Spencer, Charles V., Rensselaer Poly. Inst.
13433 Kilby, Norman M., Rensselaer Poly. Inst.
13434 Byrne, William E., Rensselaer Poly. Inst.
13435 Beers, Roland F., Rensselaer Poly. Inst.
13436 Edelstein, Ellis E., Rensselaer Poly. Inst.
13437 Webster, Theodore A., Rensselaer Polytechnic Institute
13438 Kerney, Iden, Rensselaer Polytechnic Inst.
13439 Doyle, Lee P., Westinghouse Technical School
13440 Merrick, Bently A., Rensselaer Poly. Inst.
13441 Bishop Avard M., Wentworth Institute
13442 Davis, Emery W., Wentworth Institute
13443 Zabriskie, Stanley C., Steven Inst. of Tech.
13444 Beyer, Forrest W., Ohio Northern Univ.
13445 Davidson, Anthony, Cooper Union
13446 James J., Cooper Union
13447 Koren, Harry L., Cooper Union
13448 Kraut, Maurice, Cooper Union
13449 Masin, Oldrich, F., Cooper Union
13450 Rhodes, Harold A., Cooper Union
13451 Syanka, Erhardt, W., Cooper Union
13452 Stratton Frazier O., Jr., Cooper Union
13453 Baumgartner, John J., Lewis Institute
13454 LeClair, Titus G., University of Idaho
13455 Jones, Ernest W., Newark Technical Sch.
13456 Armstrong, I. W., Penn State College
13457 Dale, Irving W., Wentworth Institute

Total 195.

OFFICERS of A. I. E. E. 1920-1921

PRESIDENT
(Term Expires July 31, 1921)
A. W. BERRESFORD

JUNIOR PAST-PRESIDENTS
(Term expires July 31, 1921) COMFORT A. ADAMS
(Term expires July 31, 1922) CALVERT TOWNLEY

VICE-PRESIDENTS
(Terms expire July 31, 1921)
CHARLES S. RUFFNER, C. E. MAGNUSSON
CHARLES ROBBINS, E. H. MARTINDALE
L. T. ROBINSON, C. S. McDOWELL

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(Terms expire July 31, 1921)
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Minnesota, Univ. of, Minneapolis, Minn.	B. C. Maine	L. C. Larson
Missouri, Univ. of, Columbia, Mo.	A. C. Lanier	F. H. Miller
Montana State Col., Bozeman, Mont.	J. L. Hastings	J. A. Thaler
Nebraska, Univ. of, Lincoln, Neb.	O. J. Ferguson	O. E. Edison
North Carolina State Col., West Raleigh, N. C.	D. A Floyd	H. W. Allsbrook
North Carolina, Univ. of, Chapel Hill, N. C.	P. C. Smith	T. B. Smiley
Notre Dame, Univ. of, Notre Dame, Ind.	Frank Miles	W. Shilts
Ohio Northern Univ., Ada, O.	E. A. Erdman	J. W. Ulrey
Ohio State Univ., Columbus, O.	S. S. Hunt	R. H. Kaspar
Oklahoma Agri. and Mech. Col., Stillwater, Okla.	R. W. Brown	C. S. Soule
Oklahoma, Univ. of, Norman, Okla.	M. C. Ross	V. Pendleton
Oregon Agri. Col., Corvallis, Ore.	F. N. Waters	W. D. Olson
Pennsylvania State Col., State College, Pa.	E. L. Schlottere	A. S. Warner
Pennsylvania, Univ. of, Philadelphia, Pa.	N. R. Guilbert, Jr.	H. C. Fehr
Pittsburgh, Univ. of, Pittsburgh, Pa.	C. W. Merritt	C. B. Bennett
Purdue Univ., Lafayette, Ind.	W. A. Clark	A. N. Topping
Rensselaer Poly. Inst., Troy, N. Y.	W. J. Williams	E. D. Rhodes
Rose Poly. Inst., Terre Haute, Ind.	F. M. Stone	W. H. Bruning
Southern California, Univ. of, Los Angeles, Cal.	G. R. Henninger	G. S. Bailey
Stanford Univ., Stanford University, Cal.	P. H. Davis	F. F. Evenson
Syracuse Univ., Syracuse, N. Y.	F. C. Barnes	R. D. Whitney
Texas Agri. and Mech. Col., College Station, Tex.	W. M. Denny	H. C. Dillingham
Texas, Univ. of, Austin, Tex.	C. H. Marshall	F. J. Domingues
Virginia Military Inst., Lexington, Va.	H. C. Land	L. Womeldorf
Virginia Poly. Inst., Blacksburg, Va.	C. Gregory	D. P. Minichan
Virginia, Univ. of, University, Va.	Clark Forrest	J. O'R. Coleman
Washington, State Col. of, Pullman, Wash.	C. Carpenter	J. Swanson
Washington Univ., St. Louis, Mo.	F. W. Schramm	E. H. Burgess
Washington, Univ. of, Seattle, Wash.	Lawrence Berg	W. H. Watson
West Virginia Univ., Morgantown, W. Va.	M. Wilcoxen	Hudson Chandler
Wisconsin, Univ. of, Madison, Wis.	R. E. Hantzsch	R. H. Herrick
Yale University, New Haven, Conn.	R. B. Morgan	C. S. Lee, Jr.
		Total 60

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Personal Observations in the Industry

President's Address*

BY ARTHUR W. BERRESFORD

IF, in the selection of a subject upon which to address you, I have gone further afield than the profession of electrical engineering, or, indeed, have seemed to go even beyond the domain of the engineer, I trust that you will not lose sight of the fact that whatever benefits industry as a whole benefits the engineer; and again, if I seem to doubt the possibility of the engineer being competent in himself to solve all of the problems of our complicated civilization, I trust you will not consider me as holding him to be without function.

It is true that I am not in entire sympathy with what appears to be a growing feeling that the engineer may, with advantage, invade all fields of effort, and I think I perceive a growing resentment toward this conception of the engineer's function. I am not at all certain that the engineer should presume to advise in the relation between employer and employe, nor that he should consider himself competent to adjust the many problems which arise in commerce and industry. Is it not possible that the qualifications of the engineer have been confused with the methods of the engineer, and may it not be possible that what is desired is the application of engineering methods rather than the engineer in person?

However, this divergence in viewpoint might be reconciled—if there be not too much of heresy in the suggestion—by assigning the title of "engineer" (although of a class not yet provided with a distinguishing descriptive adjective) to those who are doing creative work in industry and commerce based on the application of these same engineering methods. If this lack of heresy be conceded, then is what I have to say proper for your consideration.

The outstanding characteristic of the present-day civilization is organization—the almost involuntary gathering together in groups of those possessed of interests in common; usually, in the beginning, that there may be facilities for the interchange of views on matters which engage the daily thought. This is the stated object of our own organization. Sooner or later, however, the possibility of other activities becomes evident and inevitably the initial purpose of the association is broadened and work is undertaken which results in common good. In the measure in which the purpose is altruistic and the element of self-interest is lacking, or enlightened, the accomplishment benefits not only the actual members, but industry as a whole, the community and the nation, and ultimately the world in which we live.

From the instinctive nature of their conception, these associations, however well-conceived for their specific purpose, will not be formed in accordance with some well-considered and throughly-planned scheme, resulting in a properly rounded and carefully calculated whole, but, on the contrary, will present to a broad view the impression of a series of unrelated bodies, each going forward in its own way, and, to an extent, ignoring the interests they have in common, until consideration is forced by some duplication of effort or conflicting action.

This condition has long been recognized and was under discussion when I became connected with the Institute as an associate member some twenty-five years ago. The thought then was that the Institute should be the dominant body in the industry, embracing all branches of activity and permitting the concentration of all available knowledge and experience on any given problem. The possibility of such an organization, or at least of a council, in which all might be represented, is still under discussion. Progress, however, has been along other lines, and today the probabilities are that such an organization would fall because of its very breadth and its consequent inability to deal with other than the broadest problems susceptible only of the most general of solutions. There would not be the concentration of interest necessary to the accomplishment of tangible results.

The major problem of the present day is the education of the mass of the people to the perception of true values. Most of our difficulties result from the honest misunderstandings of honest men—misunderstanding of speech, act or motive—with consequent growth of suspicion and inability to evaluate

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the opposing viewpoint. This is true of the employer-employe relation. It is equally true of the competitive relation. It is no less true of the relation of industry and government. If the condition is to be removed and the interest of our whole people advanced, the only certain procedure is through adequate education. In the employer-employe relation this can be carried on most effectively in the ultimate unit, namely, in the individual plant, and by those directly interested. In the industry it can be accomplished only through the understanding that comes from contact and interchange—as between industry and government only by the presentation of mass view of the industry, setting forth adequately, accurately and honestly the general need of all.

In other than matters of direct interest, such as the employer-employe relation, the association, for whatever purpose originally devised, forms the natural and obvious means of carrying forward this process of education so vital to our future. Men meet and weigh each other. Trust is born of knowledge and there follows the death of mistrust born of ignorance. Views are interchanged and opinions crystallize. Intelligent analysis determines the underlying fundamentals and does not mistake the symptom for the disease. The diagnosis properly completed, the remedy becomes apparent, and the policies based on the fundamental principles may be followed in the certainty that their consistent and persistent observation will ultimately produce the desired result, however long the interval.

But no single association can do this for an industry. It becomes necessary that all be represented. Particularly is this true in relation with government and governmental functions. No single group—whether corporate or associate—may assume to present the interest of the whole without arousing the suspicion that self-interest is present, as at least a considerable motive. Nor can it hope to be continually successful in this procedure, however much it may appear to accomplish initially.

These statements are so obvious as to appear trite, but how frequently one hears it said that the association operates mainly to the advantage of the minor interests; that the large corporation, complete in itself is self-sufficing; that it could and does perform for itself all that may be possible through association, and that in consequence it contributes to association by far more than it receives. The essential lack of soundness in this view is immediately apparent, however, when one considers the entire industry and the relation thereto of the large corporation.

For the proper development and economical operation of any industry, the major interests in that industry must have the understanding, support and good-will of those less important. This is true in direct ratio as the policies of these major interests are enlightened, broad and far-sighted. The human instinct of caution, emanating from centuries of need for self-protection, breeds both suspicion and jealousy of power. The policies of a minor manufacturer may be directly contrary to the interests of an industry as a whole, not by intent, but by reason of a limited point of view. He would be entirely willing to reverse these if there were clearly set before him the certainty of ultimate unfortunate result to himself as well as to others, but without this understanding any instance of interfering procedure by a major interest is certain to be interpreted as an assault upon his business for competitive reasons. He will, moreover, ascribe the success of such procedures to a wrongly held and unfairly exerted power by the large corporation rather than to its true cause, and he will be sincere in this attitude. The result must be an increase of suspicion, based on misunderstanding; of jealousy and resentment, based on a sense of personal injury; of mistrust, based on fear of future repetition. All of these breed waste and destructive competition, increase the ultimate cost and reduce distribution, with consequent injury to the industry as a whole and to the individual units which compose it—whether large or small.

If, on the contrary, the major interest, by contact and consideration, secures the trust and understanding of the smaller man, and if it proceeds still further and puts before him the facts and conditions which determine its policies, which data he has neither the facilities nor the opportunity to acquire for himself, thereby increasing his understanding and broadening his viewpoint, much that is otherwise impossible becomes practicable. It may be unfair that the larger interest should be called upon for the expenditure of time, money and patience necessary to this process of education and the devotion to it—as will initially be necessary—of their best minds, but their advantage is largely concerned and their ultimate success involved. The association provides the opportunity for this procedure.

From the industry's standpoint, therefore, the problem becomes the correlation of the necessary associations into a representative coordinating body and the direction of the combined effort in such manner as shall insure such advantage to its members as is consistent with the rights of others and the best interest of the public.

It is immediately evident, however, that the securing of this advantage to an industry—to the corresponding advantage of each division thereof including that of engineering—involves the correlation not merely of engineering associations, but of all associations interested—whether commercial, non-commercial scientific, or serving some special interest.

I sometimes feel that we of the non-commercial class hold ourselves too much aloof from those organizations whose function is apparently the promoting of the material advantage of their membership. There

may be, and is, as high an idealism in industry and commerce as in pursuits termed "non-commercial," and more than one operation of magnitude has been instituted and quietly carried through with far less of thought of ultimate profit than of the service to be rendered to humanity. We have every-day instance of something done for the general good and because it is right, that bespeaks a high-mindedness which those who pride themselves on freedom from commercial incentive may well admire.

And let us not forget that in the end the major incentive to result is self-interest and that properly educated and enlightened self-interest may accomplish more than a less practical altruism, and with no sacrifice of ideals.

Our portion of the work may be to increase the percentage of idealism, while at the same time encouraging the proper operation of this major incentive of self-interest which is absent from few or none; to direct it along broad and well-considered lines of principle and policy, with the elimination of opportunism, and to the end that each may strive to profit with the other, rather than at the expense of the other. There is nothing of communism in this. The reward of each will still be a function of his effort and ability, but there will come understanding of the reasons for the disparity in reward instead of revolt against a seeming unfairness; discontent with one's self and consequent increased effort, instead of jealousy and dissatisfaction with conditions; a coordinated working along well-defined lines, rather than individual attack at possible cross purposes, arising from restricted knowledge of the problem in its entirety. That such procedure must make for the maximum of progress in whatever line of activity it may be applied is self-evident.

Our own branch of industry is peculiar in possessing all of the elements present in any other and many in addition—all of the problems of manufacture and construction, together with specific problems demanding knowledge of almost every other branch in order that proper application of our product may be assured; an extended engineering content; a dependence on pure science and mathematics by far greater than any other of which I have knowledge and a more than ordinary interest in government relation—national, state and local—by reason of public service content. What other branch of industry involves so many factors? It would seem, therefore, that could we offer a solution for some of our own major problems, we would be pointing the way for all industry and that we might anticipate its concurrence and support in what we may initiate.

I have said that the major problem of the day is education, the major phenomenon organization, and that within the industry, organization—properly correlated—furnishes the obvious medium for the process of education; the question being to secure such correlation.

I believe this correlation could be attained if the broad fundamental principles underlying the industry could be enunciated, and if there could be developed therefrom the operating policies which the industry should follow. The proper and adequate performance of this task would secure the assent of all elements, and while permitting each organization to preserve its individuality unchanged would direct procedure along parallel lines leading toward the common goal. The points of common interest would be quickly and conspicuously developed and cooperative, harmonious relations thereon instinctively established.

Who is most competent to perform this task? It seems to me that there will be required the best minds of the industry—the men of the broadest viewpoint and experience and of the widest contact with all of the phases of our work. Where shall we look for such men? It is my opinion that they will be found in the executive personnel of our great corporations. The constructive ability, knowledge and grasp of affairs, keen perception of values and idealism which have put these men in these positions, and without which there could have been no such accomplishment, must result in their becoming the leaders, and, in the main, the doers of this work. That they could in no way more surely serve their own interests is beside the point. If they undertake it, they will do so from the broader viewpoint of rendering that service to their fellows for which they are the best qualified. That they will undertake it, I believe.

Assuming such a correlation, let us develop one or two of the problems which confront our own industry, and, in varying degree, other industries, and apply the factors which we have been considering. The appreciation of the ultimate dependence of industry on science and the consequent vital importance of research is of too recent birth to have attained general realization. The statement is accepted as a matter of course, but it has not come to be an actual, living, daily reality in the minds and life of most of us. That it will ultimately be so recognized is certain, and possibly in the near future. This being the case, how are we providing for it? The larger corporations are maintaining research laboratories—have been forced to do so by the demands of the industry—in which the bulk of this work has been directed toward the solution of specific problems, the results of which are generally conceived to be for the benefit of the corporation individually, and in part may be so initially.

The universities are carrying on research work in their laboratories to an extent determined by their financial resources and the initiative of their personnel; mostly of abstract nature, directed to the solution of general problems, chosen largely, and sometimes I think mistakenly, for the absence of applicational content.

The Bureau of Standards, under government auspices, and in the interest of the country's industry, is performing work of both types.

There are certain privately operated laboratories whose services may be employed by the industry in general for the solution of specific problems.

To determine how the work as a whole should be correlated to secure the maximum progress requires an understanding of the conditions.

The first conception which it seems necessary to establish is that all research is in the public interest—whether applied or abstract, and irrespective of whether its immediate object is the specific advantage of the concern or person undertaking it, or simply the increasing of the sum of human knowledge.

No one will question that abstract research, forming, as it frequently does, the foundation of important industrial advance, and given to the world without restriction, is definitely in the public interest. There may be those who question the content of what may be termed "practical applications" and who would limit investigation to the more promising possibilities, but the past gives ample warrant for future expectation, and no man can say in advance where value may be found. Much that today seems of no practical value may simply be awaiting the key discovery which will be found by no process other than that of this constant search for fundamental truth.

The misunderstanding seems to lie in the so-called "applied or applicational research," usually directed toward a specific problem, the solution of which becomes, under our patent system, the exclusive property of the instigator and a consequent source of gain. Is not this as it should be? Without this incentive no corporation could justify to its stockholders the necessary expenditure, and but few individuals would possess the necessary resources; for not every problem is solved and many months are spent in work that brings no fruition. Moreover, the period of exclusive use is limited and but short compared with the time during which the solution may ultimately be freely used by all. Again, the public as a whole usually reaps the benefit of the solution during this period of exclusive use and is advantaged in such degree as to make the reward to the owner small in comparison. A corporation laboratory produces ductile tungsten. During the life of its monopoly its profits may be great, but they are insignificant compared to the millions that are saved to the many who employ it in the incandescent lamp during this period, which savings will continue in effect long after the period of exclusive use is past. An improvement in the art of speech transmission may result in increased gain to the corporation controlling it, but it decreases the cost of the telephone to the user (or increases his possibilities at a given cost) even while the patent monopoly continues, and thereafter for all time. This is true in some degree of every successful applicational research.

It becomes clear, therefore, that *all* research is in the public interest, and that from the public viewpoint the sole difference in desirability between abstract and applied research is one of degree and not of fact; that the important point is increased research activity irrespective of where or by what means it is carried on.

There are two prime incentives—direct gain and the search for truth—the first more immediately productive of usable results, but aiming at what may be termed the details—the second laying the broad foundation for the future. There is no middle ground. No one can say at what instant an abstract research may develop an important practical application, and *vice versa*. The division between the two fields is a sharply defined line, not a neutral territory. It is fixed purely by the motive which animates the work. It is all of equal importance to the public and to the industry. It is comparatively unimportant how it is carried on and whether for a brief space someone shall be peculiarly advantaged.

In feeling that industry must supply the driving force, I am not setting the hope of gain as a greater impulse than the search for truth, but means must be supplied and to industry, the producer, we naturally turn. The hope of gain will impel the continuance of applied research where it is already established, and, where the individual concern cannot support its own adequate facilities, will widen the field by the institution of laboratories for the common use of groups possessing similar interests, once its value is appreciated. We may confidently expect, therefore, that this division of the field will show increased intensity of cultivation in direct ratio to the realization of its possibilities.

Fundamental research, however, must be provided for. The search for truth will supply the incentive, but not the means. Universities will do what their poverty permits, but it is not sufficient. Industry must increase the possibilities. An incentive must be offered to induce temperamentally fitted men to undertake this career and to become largely qualified, else industry will go begging for the men it will need in increasing quantity for its applied research. It may fairly be said that this condition is with us today, and that with the increasing demand there is danger that the universities will lose in practical totality those who must be depended upon to keep alive the spirit and train the men who are up-coming. Men now exist, in reasonable number, whose devotion and achievement in this field are an inspiration and an example for emulation among their co-workers which is of far-reaching effect. Given even a minimum of encouragement the future will continue to evolve them, and once in a generation or so a genius.

In the general consideration of such men in relation to organization, may I divert for the moment and offer a word of caution? Genius works not too well in harness and are there not already, both here and elsewhere, indications of a feeling that too much centralization and coordination may hamper or even cripple rather than facilitate?

I know of but one instance (there may be others) in

which industry has begun formal consideration of its relation to research in the universities. In February, 1919, the Michigan Manufacturers Association brought to the attention of the regents of the University of Michigan the desirability of establishing closer relations between the university and the industries of the state, realizing that in so doing an appreciable degree of cooperation would be through channels of research. The Regents' Committee considered the matter and favorable action was taken in January, 1920. The first meeting of a combined committee was held on May 27, 1920, and that committee is busied with the many questions involved. Where state universities exist no action could be instituted which promises more of ultimate value to the community.

If, then, industry must take the initiative, if only in its own interest (although I believe the action will be on broader grounds once the condition is appreciated) can it again do better than to secure the concentration upon the problem of the best minds that it possesses and to determine what is to be the relation and what course to pursue? I conceive that those most competent to form such an opinion are those who have the broadest knowledge of our industry and the largest experience with the problems and advantage of research, and again I conceive these men to be the best minds in our major corporations, irrespective of position—whether commercial, engineering, or purely scientific.

Consider the governmental relation as existing between the industry and the Bureau of Standards, in whose operations, by reason of our diversification, we have more than ordinary interest. During the last few years, I have heard many expressions of dissatisfaction with certain Bureau actions and activities, and have heard various causes assigned, among which were the belief of an existing total misconception on the part of the Bureau of its proper relation to the public; a feeling that the Bureau construes its function to be that of protecting the public against some possible unfair act or aggression of the so-called corporate interests, and that in consequence there is being bred in its people an unjustifiable suspicion of, and antagonism to, those who are engaged in operations for profit, and a lack of recognition of the fact that they also are part—and a useful part—of that same public; that this misconception, together with a seeming need for the initiation of activities which should directly appeal to the popular mind in order that appropriation committees might be impressed, are carrying the Bureau beyond its proper scope and into fields of work for which it is ill-fitted—which fields could be covered to far greater advantage by other agencies and methods—and that in consequence distinct damage is being done. Doubt is even expressed of the actual desirability of the Bureau.

These are formidable allegations and must have their foundation in some measure of truth or in misunderstanding. In any event, they are serious and if either the conditions or the misunderstandings are not eliminated, definite harm will result.

The conception of the elimination of the Bureau is surely exaggerated. It requires but little consideration to determine that the maintenance by the government, and under conditions beyond suspicion of improper influence, of a central authority, dealing at least with weights and measures, is essential. That the scope of such an activity may well be extended beyond so limited a function seems equally evident. My own conception is that it may helpfully be broadened to the determination and establishment of all matters of physical fact, but that it should stop short of matters of opinion or economics, but I may be too conservative. The obvious condition is that divergence of opinion exists, and that there will be increasing lack of harmony unless this divergence is removed.

The Bureau has undoubtedly devoted much thought to the course it has adopted. How much real consideration has the industry given to the subject? Is not the situation an instance of two groups, each proceeding along its own preconceived line, until the attention of each is concentrated on the other by an apparent conflict of interest? If the scope of the Bureau's work is of direct interest to the industry—and it seems to me to be of vital interest—then is the situation sufficiently serious to demand the most careful consideration of the industry—and sufficiently acute to demand it immediately.

As to the personnel of the Bureau, I know of no more unselfish, self-sacrificing, patriotic body of men. I have yet to meet one who has given his personal interest even the consideration it merits. If these men are not proceeding along the most helpful lines, it is because of a mistaken conception of what is their duty. Whatever they are doing, they are doing honestly, and there is always a complete willingness to discuss freely and fairly any objection which may be urged. If such misconceptions exist, how much has the industry done to correct them? These men are not of commercial type, nor are they in touch with affairs. How is it to be assumed that they will, out of pure instinct, foresee all of the effects on our complicated industrial structure of some activity undertaken by them in all honesty and apparently in the interest of all? To what extent has industry striven to make clear its condition, instruct the Bureau in its problems and convince the Bureau of its good faith? Is there any other method of curing whatever undesirable condition may exist in this respect?

Again, if there actually exist conditions which have induced what industry may consider as an undue expansion of the Bureau's field in order that the importance of the Bureau may be enhanced in the minds of members of Congressional Appropriations Committees,

then is not the industry to blame for these conditions? If, in the interest of the farmer, it is deemed necessary and desirable that millions be spent in agricultural research—and not only public opinion, but the results of record affirm the wisdom of this expenditure—is it not incumbent on industry similarly to make clear to the government its needs and demonstrate to it and to the public the importance and necessity of meeting them? The amount required is far less than the expenditure for agricultural research and the value of the products affected is of at least the same order. Is it consonant with the dignity of the Bureau and the men who give their lives to its work that they should be obliged to manoeuvre for the necessary support, and that when given, it is so meagre that the work is hampered and the men themselves so poorly compensated that many, contrary to their own desire, but purely that their families may live in reasonable comfort, have been obliged to terminate their career of public service and take up more gainful occupation? I conceive it to be the prime duty of the industry, first, to agree on what shall be the scope of the Bureau; second, to educate the Bureau in its conditions; and, third, by demanding that its interests be heeded, to secure the adequate support of the Bureau.

Only a united industry—commercial and non-commercial—can do this. The electrical industry, by reason of its greater interests, should initiate it and carry forward, through its associations, the necessary process of education; and, again, I believe that these same leaders of the industry are most competent to determine the fundamentals and the policies by which we should be guided.

My conception, then, is that the immediate need of the industry is the enunciation of what are its fundamental principles, the statement of what should be its working policies and the outlining of what should be its relation to the major problems which confront it; that there is a sufficiency of organization and of interrelation of organization; that there should be added only cooperation for specific objects where progress or legitimate interest directly indicates its desirability; that the matters in which this cooperation may be applied and the agencies between which it is necessary will be made evident only by the broad analysis suggested; that once made evident it will be instinctive, effective and efficient.

There may be disagreement with my feeling that this analysis would best be made by men in the corporate relation and the thought may be that it would better be done by conference of the industry's organizations, since if this procedure were followed any suspicion of an undue degree of self-interest would be eliminated; but I ask consideration of how cumbersome would be the procedure and how small the probability of reasonable expedition in reaching results. The mere fact that numbers of men would be engaged instead of four or five would make for extended deliberation, and time is an essential element. Moreover, it is evident that the prononucement, when made, would be accepted by the industry only in the degree that it embodies the breadth of view and the knowledge which these men possess and the honesty of purpose which I am certain they would bring to the task. My belief is that it would be thoroughly acceptable. It is no small service to ask of them, but again I am confident that it will be rendered willingly if the industry realizes its importance, agrees as to the method and makes the request.

STANDARDIZATION OF ENGINEERING PRODUCTS

A conference, unofficial in character, of the secretaries of the various standardizing organizations at present in existence was recently held in London. The conference was opened by the chairman of the British Engineering Standards Association, Sir Archibald Denny, Bart. The following secretaries were present:—Dr. P. G. Agnew, U. S. A.; Mr. A. Erikson, Norway; Mr. E. Hijmans, Holland; Mr. J. R. Durley, Canada; M. G. Gerard, Belgium; M. Zollinger, Switzerland; and Mr. C. le Maistre, C. B. E., Great Britain. The object of the conference was the exchange of ideas tending towards the establishment of closer relationship, and from that point of view it was eminently successful. Each secretary gave a brief report of the general organization of the work in his country and the methods adopted in arriving at the standards, as well as the principles followed to ensure their adoption when issued. * * *

Some enthusiasts are rather apt to think that the time has arrived to attempt to create an international organization for standardizing all engineering products; but the conference, it is understood, took a much more modest view and, seeing the almost insuperable difficulties in the way, preferred to see international standardization develop along national lines and sectionally, similar to those adopted, for instance, by the electrical industry in the case of the now well established International Electrotechnical Commission. The Conference having no executive functions whatever, each secretary will in due course submit to his respective organization the suggestions of the conference on the various points discussed.

The secretaries were entertained by the British Engineering Standards Association during their four days' conference. The human factor enters so largely into all questions of standardization that the meeting of the secretaries of these important bodies, * * * is bound to be of no small advantage in the future and materially assist in guiding international intercourse on this complex question along right lines. —*The Engineer*, London.

Hydroelectric Development at Niagara Falls

BY JOHN L. HARPER and J. A. JOHNSON

Both of The Niagara Falls Power Company

THE PURPOSE of this paper is to trace briefly the progress in the art of power development at Niagara Falls from its beginning to the present time, to describe more particularly the recent developments and those about to be undertaken under the recent license granted to The Niagara Falls Power Company by the Federal Power Commission, and to indicate the present and probable future functioning of Niagara power in the industrial development of the country.

The physical conditions existing at Niagara Falls are not duplicated elsewhere in the world. The immense drainage basin of the Great Lakes contributes an almost uniform outflow of water of such magnitude that the question of adequate supply is not one which need be considered for many years to come. This continuous flow of over 200,000 cu. ft. per second, finds its outlet through the Niagara River which falls through a total height of 336 ft. between the Lakes Erie and Ontario. Of this 336 ft., 165 ft. is concentrated in the cataract itself and another 55 ft. is in the rapids immediately above, so that within a distance of one mile there is available a total head of 220 ft.; or, combining the 94 ft. of drop in the lower Rapids with that above, there exists a head of 314 ft. which may be developed within about five miles, distances being measured on the American side of the river. This flow of water and the natural head available provide a source of power of over 6,000,000 h. p. which, under ordinary conditions, one might expect would be used to the full for industrial purposes.

One factor alone has prevented the perfect working of economic law in this respect, and that factor is the value of the cataract and rapids from the scenic standpoint. That this value is a real one, no thoughtful person will deny. "Man cannot live by bread alone," and who can doubt that God who, in His infinite wisdom, gave us Niagara, intended it to minister to the spirit as well as to the body of mankind.

This division of Niagara's ministration between the material and the spiritual, has always existed since Niagara became known to civilized man, but it is just beginning to be recognized that the division must ultimately be made at that point where the sum total of human benefit shall be a maximum. And when that point is finally determined, the portion of the energy which is found not necessary to maintain the spiritual values will undoubtedly be made available for industrial purposes.

As early as 1725, nearly 200 years ago, a primitive sawmill made first use of Niagara power, and 100 years ago small waterwheels were used in mills located along the upper rapids on the shore and small islands of the American channel; but these early developments have long since disappeared and very little evidence remains to show that they once existed. A short piece of the original headrace is now converted into a scenic pool just upstream from the Goat Island bridge, and the size and nature of these mills is indicated by the accompanying illustration (Fig. 1).

The beginning of the existing power developments may be placed as far back as 1852, when the construction of a hydraulic canal was begun, extending from a point at the head of the rapids above the falls, now known as Port Day, to the edge of the gorge a mile below. In spite of the fact that the land for the right of way had been donated by the Porter family who then owned most of the land bordering the Falls, lack of funds caused a suspension of the work in less than two years. However, it was resumed in 1859, and by 1861 there was completed a canal from 20 feet to 36 feet wide and about 8 feet deep, extending from Port Day to the present canal basin at the edge of the gorge in the same location as the present Hydraulic Canal of The Niagara Falls Power Company.

FIG. 1—VIEW FROM GOAT ISLAND

Looking toward the American shore before the establishment of the Niagara Reservation, July 15, 1885, showing paper mill on Bath, now Green Island

Owing to the industrial depression caused by the Civil War no use was made of this early canal for years although a small stream poured over the cliff unused.

In 1872, however, an installation of 150 h. p. under 25-ft. head was made for driving a grist mill. In 1877 the canal property was purchased by Jacob F. Schoellkopf and others who organized, in 1878, the Niagara Falls Hydraulic Power and Manufacturing Company. Soon afterwards the Schoellkopf-Mathews flour mill was constructed and equipped with 900 h. p. undes 50-ft. head. Four years later the head on the mill wat increased to 86 ft. which at that time was the highest

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head used at Niagara. Quite recently some sections of the iron flumes, 9 ft. in diameter, which were the first iron penstocks used at Niagara Falls, have been removed to make room for the works in the latest development.

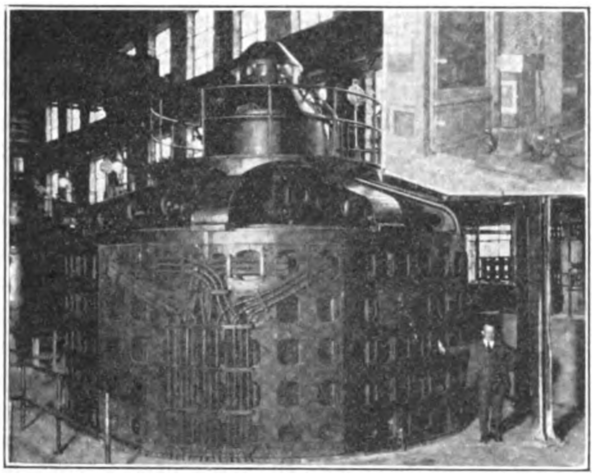

Fig. 2—Earliest and Latest Commercial Generators to Operate by Niagara Power

From this time on the Hydraulic Canal was used for supplying water power for manufacturing in important mills. The general method of development was to sink shafts or pits under the mills at the edge of the cliff, taking the water from the canal through flumes and penstocks to turbines at the bottom of the pits

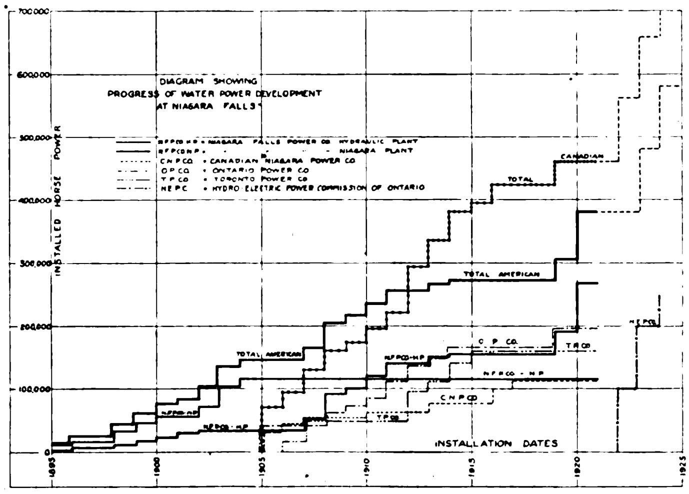

Fig. 3

and allowing it to discharge from short tailrace tunnels part way down the face of the cliff. The waterwheels were directly connected to vertical shafts which drove the machinery in the mill above.

In the year 1880 the first hydroelectric unit was installed at Niagara Falls, in Prospect Park. This unit, comprising a waterwheel and a d-c. brush dynamo, was used for illuminating fountains in the park by means of two arc lights. Excursions were run from various parts of the country to see the new wonder. This unit has little more than historical interest and diligent search has failed to reveal any photograph of the installation or any technical data concerning it.

The second hydroelectric development and first commercial installation was made in the year 1885 in

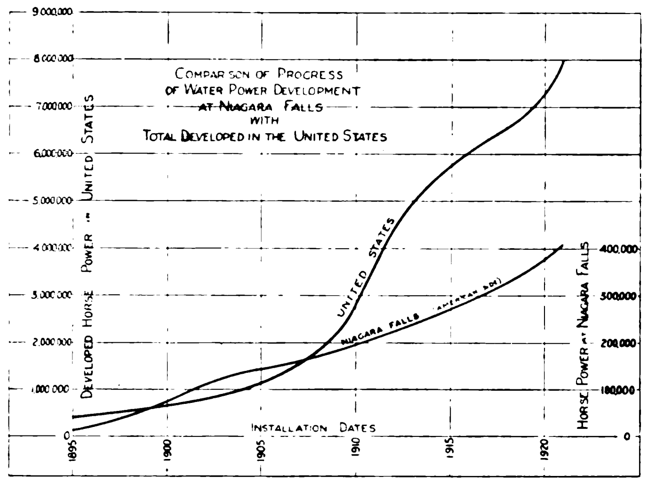

Fig. 4

the Pettebone Mill on Bath Island. The generator of this unit, which was used for lighting the mill, is shown in the insert in Fig. 2. It was a d-c. machine, having a capacity of 16 amperes at 110 volts. It is interesting to note that the capacity of the latest generator operating at Niagara Falls is about 15,000 times as great as this one. The contrast is shown in the illustration.

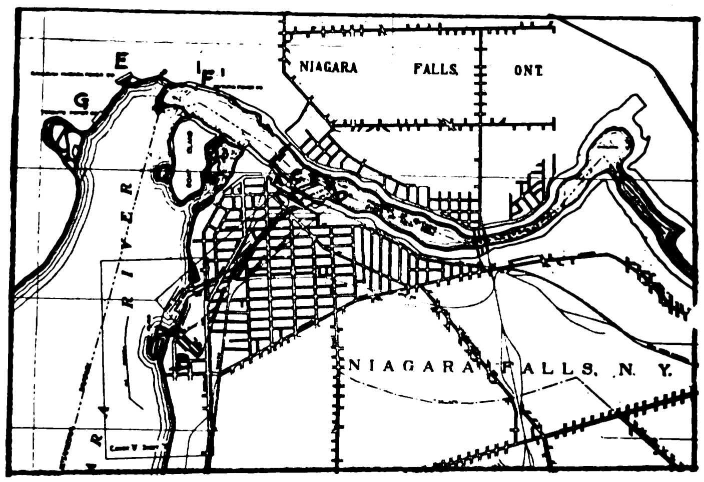

Fig. 5

As soon as these early installations had demonstrated the possibilities of electrical power, the real hydroelectric development began, and in the year 1891 The Niagara Falls Hydraulic Power and Manufacturing Company began the construction of its Station No. 1, in which dynamos were installed, operated by rope drives from waterwheels and having a total output of 2000 h. p. which was used for supply-

ing electrical power for commercial purposes. This station was abandoned in the year 1904.

In 1886, or about the time the second hydroelectric development referred to above was begun, The Niagara Falls Power Company was organized with the intention of developing hydraulic power only, the power to be delivered from the waterwheels direct to the shafting in the mills to be located along a head-race about a mile above the falls, and the tailwater to be collected in a low level tunnel draining into the lower gorge. Negotiations for the construction of the works were not completed until 1889, at which time it became clear that concurrently with the development of hydraulic power, the company could proceed with the development of electrical power and transmission. So successful was the early use of electrical power that a decision was reached in the year 1890 to install three hydroelectric units of large size, each having a capacity of 5000 h. p. A step-up transformer station and 11,000-volt transmission line to Tonawanda and Buffalo were also undertaken. Power from this station was delivered at Niagara Falls in the year 1895, and at Buffalo in 1896.

By this time the hydroelectric power development was fairly under way, and Fig. 3 shows the progress from then on up to the present time. Fig. 4 shows a comparison between the rate of progress in hydroelectric development at Niagara Falls and that in the United States as a whole. From this comparison it will be noted that progress at Niagara has not at all times kept pace with that of the country in general.

The period from 1895 to 1905 might be called the "Decade of Progress" in power development at Niagara Falls, when the various companies at work on the American and Canadian sides devoted themselves to overcoming many natural difficulties and to the building of what were then the largest plants in the world.

About 1905 the Niagara Falls Power Company had completed its American plant, marked *B* on Fig. 5. The Hydraulic Power and Manufacturing Company had abandoned its Station No. 1 and completed its Station No. 2, marked *A* and *C* respectively; and in addition other plants were well under way, namely Station No. 3 of the Hydraulic Power Company, marked *D*, and the three plants shown on the Canadian side marked *E*, *F* and *G* belonging respectively to the Canadian Niagara Power Company, the Ontario Power Company and the Toronto Power Company.

These plants have been described so often that no doubt they are quite familiar to all engineers and it will be unnecessary to refer to them in detail. It will be noted, however, that three different types of waterways were employed, *A*, *C* and *D* utilizing a surface canal, *B*, *E* and *G* wheel pits and tailrace tunnels, and *F* pressure pipe lines and open tailraces. The type of waterway determined to some extent the type of machinery; plants *A*, *C*, *D* and *F* being able to use horizontal shaft units with journal type bearings, and plants *B*, *E* and *G* being forced to adopt long vertical shafts with the then less desirable thrust bearings for supporting the weight of the revolving machinery.

In the year 1906 the Governments of the United States and Canada became alarmed at the rapid improvements in the art of power plant building by which the Falls of Niagara were being made to serve the needs of man and its consequent diversion of water from the cataract, and after due deliberation the Burton Bill and the International Waterways Treaty made it unlawful to divert more than a specified quantity of water for power purposes, namely 20,000 cu. ft. per sec. on the American side and 36,000 cu. ft. per sec. on the Canadian side. In this negative way it was hoped to save the great spectacle from destruction.

These laws cast a blight upon the development of the art at Niagara Falls and the period from 1906 to 1916 might properly be called the "Decade of Stag-

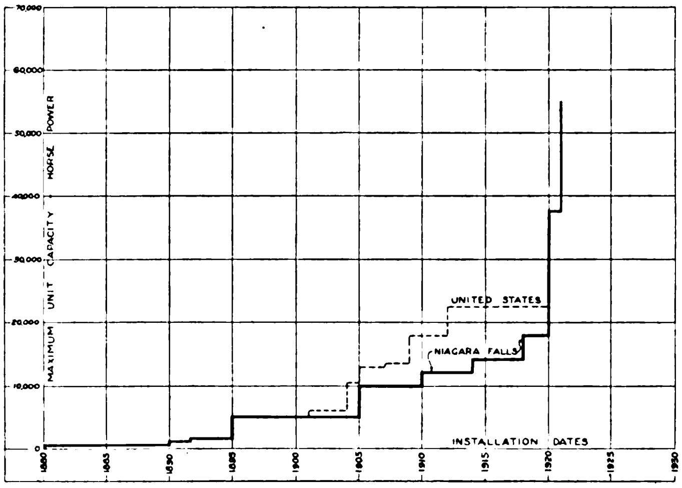

Fig. 6

nation." It is quite true that additional units were installed in the existing plants during this interval, but with no future to look forward to there was little incentive to improvement, and little attempt was made to keep pace with the advances being made in other parts of the world. The plants were completed for the most part in very much the same manner as they were begun in 1905.

As an indication of the foregoing, Fig. 6 shows how the development at Niagara Falls lagged behind the progress being made in other parts of the United States in regard to the size of units being constructed, until finally in 1918 Niagara Falls was restored in this respect to its rightful position of first place.

During this time Public Opinion in regard to Niagara Falls found expression along two diverging lines of thought, one claiming that diversion for power purposes would ruin the scenic grandeur of the falls and therefore should be stopped entirely, the other

representing those interested in the work at the falls, who insistently pointed out the folly of attempting to save the falls from destruction by allowing them to destroy themselves. As year after year went by it was apparent that 6 to 8 ft. of yearly erosion at the apex of the Horseshoe amounting to at least 60 ft. in ten years was doing more to draw the water from the sides of the Horseshoe and destroy its beauty than all

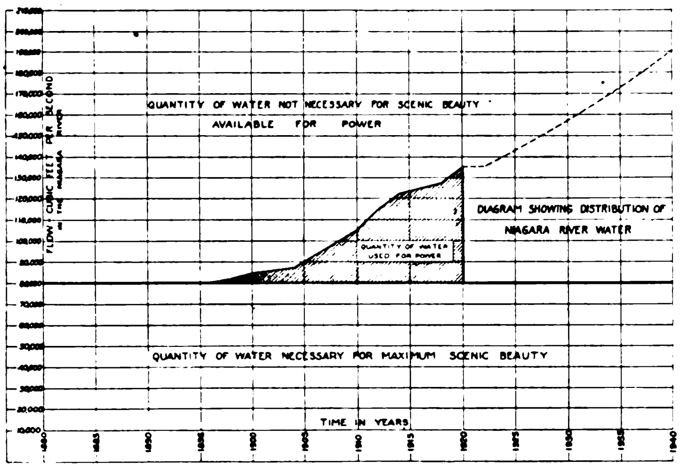

Fig. 7

the power plants put together. Once this fact was realized the remedy became self-evident. It is now recognized that by far the greater part of the water in the river not only contributes nothing toward the scenic grandeur but rather tends to detract from it by sending up clouds of spray to obscure the otherwise beautiful sight; and not only that, but is actually destroying the scene by erosion. Instead of arbitrarily restricting the amount of water which may be diverted for power purposes, the sensible thing to do is to adopt some measures that will spread so much of the water as is required for scenic beauty evenly over the crests of the falls and to divert all the rest for power purposes, thereby conserving for all time and to the greatest extent both the spiritual and the commercial values. This division of the flow for scenic and power purposes as recommended by Government engineers is shown in Fig. 7.

During the war emergency and at the suggestion of the representatives of the War Department, the Niagara Falls Power Company, Hydraulic Power Company of Niagara Falls and the Cliff Electrical Distributing Company were merged under the name of The Niagara Falls Power Company, but under the control and management of the owners of Hydraulic Power Comapny, the merged interests owning all the developments on the American side and controlling the Canadian Niagara Power Company on the Canadian side. These plants had a total installed capacity of 350,000 h. p.

Under this unity of control and direction, a plan was quickly evolved not only for immediately placing all developed power at the disposal of the Government agents for distribution to specified customers who were making the materials vital for war work, but also for the rush development of another 100,000 h. p. without sacrifice of permanency of work or efficiency of conversion. These construction plans were being rushed to completion when the signing of the armistice made speed less important; however, the whole 100,000 h. p. was put in operation within 22 months from the time they were authorized.

Shortly afterward, however, the Government of the United States established the new Federal Power Commission, one of whose first acts was to give approval to the plans being carried out by The Niagara Falls Power Company and to issue a license to the company for all the water permitted to be diverted from the American side of the falls in accordance with the terms of the existing treaty. At the same time it recommended an increase in the allowable diversion and the construction of remedial works to preserve the beauty and grandeur of both the American and Horseshoe Falls.

This license gave formal federal approval to the plans of development already begun, and authorized their completion. These plans include the placing in reserve of the present Niagara plant marked *B* on Fig. 5, the construction of a new waterway from Port Day to carry the water now being used in the Niagara Plant to the Canal Basin, the maintenance of Station No. 3, marked *D* on Fig. 5 with its 13 effi-

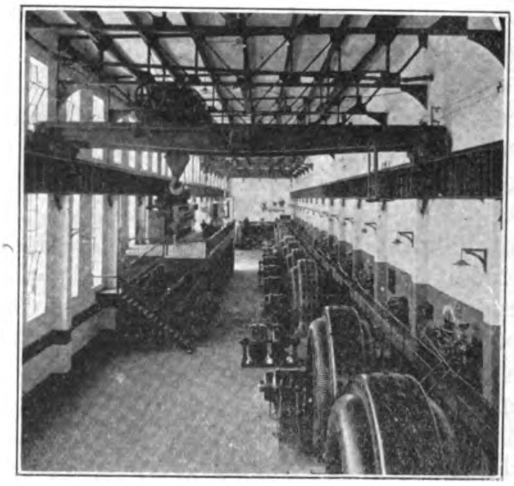

Fig. 8—Interior of Station No. 3 Generator Room

cient 10,000 h. p. units operating under a mean gross head of 217 ft. (see Fig. 8), the extension of this Station to the southward and the construction of new units to utilize the 4400 cu. ft. per sec. of water that had not been specifically allotted under the treaty and the water now being used by the Niagara plant. Plans were made so that subsequently the water used by these plants may be re-collected at the most favorable point and carried by tunnel past the lower rapids to a

power house in the lower river where the remaining head may be developed.

The first step of this general plan has already been carried out, namely the construction of what is known as Station No. 3 Extension, marked *H* on Fig. 5, begun in 1918 as a war measure and finished in 1920. This extension contains three units, the combined rating of which is 100,000 h. p., and, together with the other plants of the company, uses all the water allowed by the treaty. The second step has just been authorized, namely the construction of a new tunnel and the installation of the remaining units in an addition to Station No. 3 Extension, marked *K* on Fig. 5.

The third step also has been initiated by the granting of a preliminary permit to The Lower Niagara River Power and Water Supply Company, which allows two years for the presentation of plans for the second or lower river stage of the development. The details of this plan have not yet been worked out and the date of its contruction has not been finally decided upon.

Much has been said about the desirability of using the diverted water under the full head of 314 ft. from the upper river to Lewiston, and when the field is entirely without complication, as in the case of the development of water in excess of the present treaty allowance, a one-stage development will undoubtedly be advisable. The reason for the apparent rejection of this plan for the present diversion may be of interest. As a matter of fact, the scheme of development now being carried out does contemplate the use of the full 314-ft. head, but instead of utilizing this head in one plant with a long new waterway involving the abandonment of the efficient plants already built, it will be utilized in two successive stages, the first stage utilizing a gross head of 220 ft. and the second stage a gross head of 94 ft.

Broadly speaking, the commercial power capacity of the two-stage development is practically the same as that of the single stage, such slight theoretical differences as exist being in a practical sense unimportant. The problem then has been to decide whether the interests of the power consumers, and indirectly of the public, would be best served by an eventual total abandonment of all the plants that had already been built and the construction of a new plant to utilize in a single drop under the full 314 ft. head, the total quantity of water permitted to be diverted under the treaty, or, by conserving as much of the old work as could be conserved without impairing the general efficiency of the use of water and the construction of new works to supplement the old. It is an axiom that whether a power development is constructed with private or with public funds, the consumer pays the cost. A breach of economic laws, therefore, must be immediately reflected in increased rates. A careful study was accordingly made to determine the most economic development, particular attention being paid to the vital factor of interest on the investment during construction and on the unutilized portion of the new works during the period of business development, items which run into millions of dollars owing to the long time required to build and secure a market for these large developments. The general conclusions of this study are expressed in the plans above outlined.

The gradual advance in the efficiency of the Niagara power developments is shown in Fig. 9. This chart is very interesting. The left-hand end of the horizontal lines shown for each of the developments, indicates the earliest date at which the corresponding efficiency was obtained, and the smooth dotted curve made by joining these points is quite remarkable as showing the regular working out of the law of diminishing returns in the progress of these developments. The growth of efficiency, particularly as to those plants employing the headrace canal type of development, seems to have worked itself out according to quite

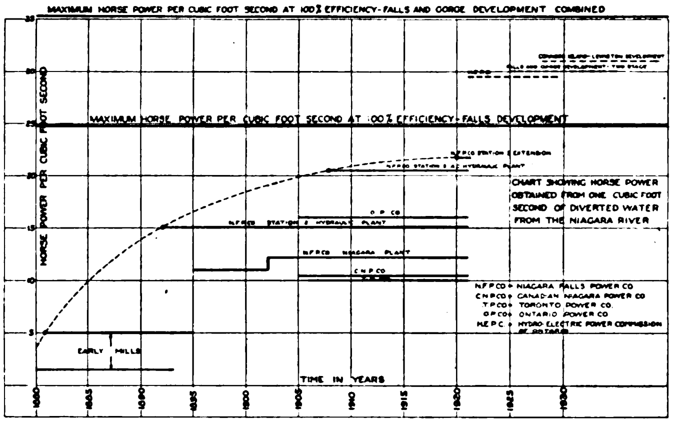

FIG. 9

a definite law and shows the inevitableness of the lack of efficiency of the earlier plants. This curve, provided that it holds for the future as for the past, also indicates the great unlikelihood of any considerable further gain in efficiency, and the probability of a very low rate of obsolescence for Station 3 and Station 3 Extension.

It will be observed that the rate of obsolescence of the earlier Niagara power developments was fairly high, decreasing however, for the later developments, as the art has progressed. The question then naturally arises as to what rate of obsolescence may be expected for this latest development. Obsolescence is undoubtedly a function of efficiency, defining that expression in terms of power and cost, and involves two factors, namely, general operating efficiency, which is promoted by the use of compact stations with large reliable units of similar characteristics; and efficiency in the use of water, which latter again involves first, the development of the maximum available head and second, careful design to get the maximum possible power out of the available water at the head developed.

These curves show very clearly how the develop-

ment of the art quickly ran through the early stages when only very small units were built, of diverse characteristics, and when only a small part of the available head was utilized, and how such plants rapidly became obsolete on account of the great gain to be obtained by building larger and better designed units under higher heads.

Analyzing this latest development in the light of these considerations we find, first, as to the efficient

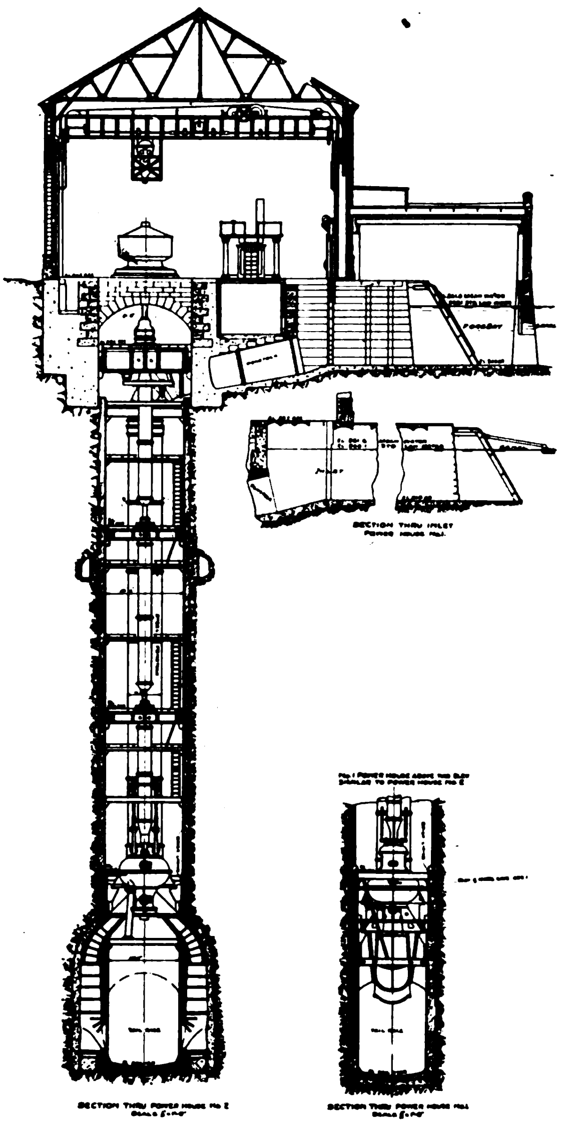

FIG. 10

use of the site, that the entire available 220 ft. has been developed with less than 2½ per cent loss in getting the water to the penstocks; second, that of the power available at the penstock entrances, over 91 per cent is delivered in the form of electrical power at the generator terminals; and finally, that although the size of future units may be increased, such increase of size being permissible when the system of which they are a part increases, there is relatively little more to be gained either in lessening cost or cheapened operation, the present 100,000-h. p. three-unit extension requiring but three men per shift to operate it.

These results are so far in advance of previous installations and leave so little room for improvement that is appears justifiable to say that obsolescence of

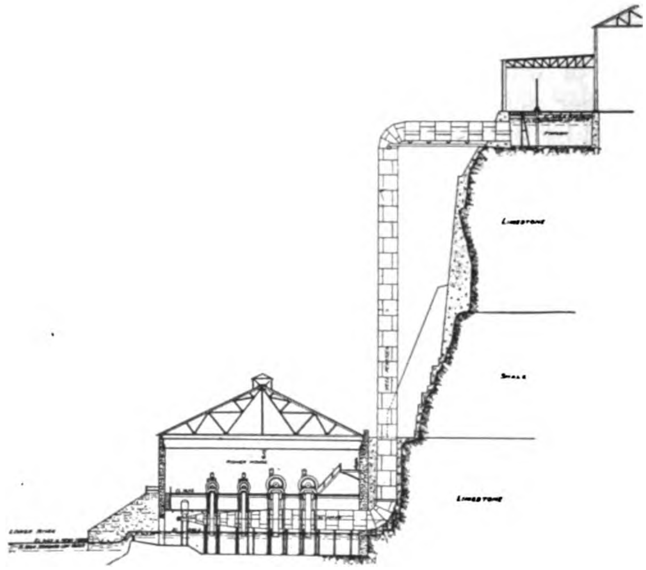

FIG. 11—CROSS-SECTION—STATION NO. 2

this plant could be brought about only by some scientific advance in the art of power production of a totally unexpected and revolutionary character.

The recent investigation and report on Niagara conditions by Col. J. G. Warren and its analysis by other federal engineers has supplied a long felt want of authentic data, and has answered with peculiarly

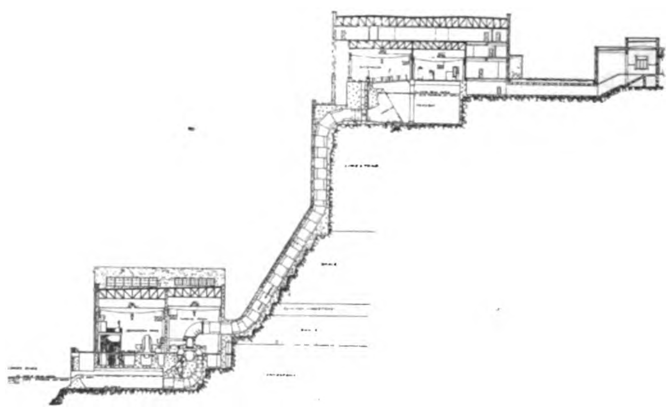

FIG. 12—CROSS-SECTION—STATION NO. 3

disinterested wisdom many of the hitherto perplexing questions in regard to comparison of plans for developments, and also as to the amounts of water necessary for maximum scenic grandeur and the amount that can be released for power purposes. This compilation of data and the well thought out conclusions therefrom, made it possible for the Federal Power Commission to come to a quick determination of the proper form of development to be adopted, which was expressed

in its first license which was issued to The Niagara Falls Power Company on March 2, 1921.

The nature of the developments made on the American side at Niagara, prior to 1918, are shown by Figs. 10, 11 and 12. Fig. 10 is a typical cross-section of the Niagara Plant (formerly The Niagara Falls Power Company) shown at *B* in Fig. 5. Fig. 11 is a cross-section of Hydraulic Plant, Station No. 2. Fig. 12 is a section of Hydraulic Plant, Station No. 3.

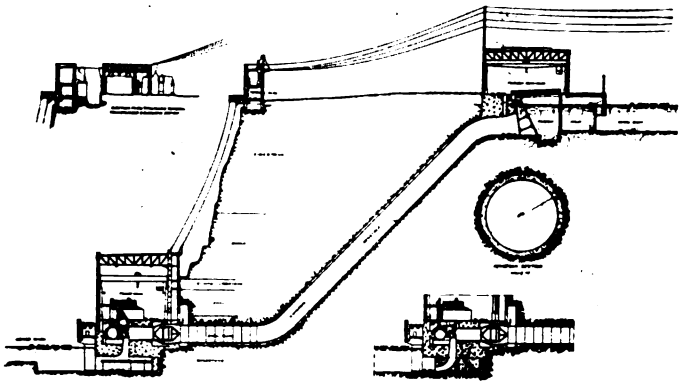

Fig. 13—Cross-Section—Station No. 3 Extension, Existing and Proposed

Latest Completed Development

The latest development known as "Hydraulic Plant, Station No. 3 Extension," which is the first section of the work authorized by the license from the Federal Power Commission, is shown in similar section in Fig. 13. The three plants shown in Figs. 11 to 13 are all located in the gorge on the bank of the lower river about half a mile below the falls as shown at *C*, *D* and *H* in Fig. 5. A plan view of Station No. 3 Extension, showing its relation to Station No. 3, is shown in Fig. 14.

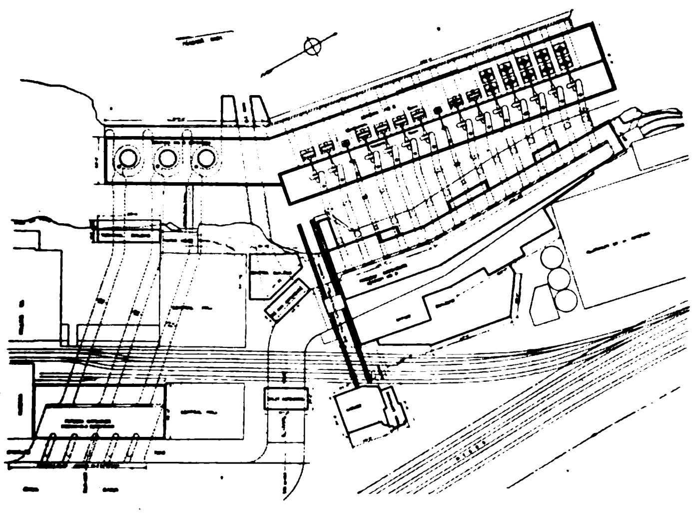

Fig. 14—Plan—Station No. 3 and Station No. 3 Extension

This development was designed to utilize the 4400 cu. ft. per sec. of water which was still available under the treaty. It consists of an extension to Station No. 3 containing three units of 37,500 h. p., maximum rating. To distribute this power it was necessary to construct a distributing station three miles away to which the power is transmitted from the generating plant by overhead lines.

In order to get the water out of the river and delivered to these units, it was necessary to make more adequate provision for ice protection at the intake at Port Day, which work is shown in plan in Fig. 15. These improvements comprise a channel dredged in the river bottom extending out into the river a distance of approximately 3000 ft. and a new ice deflecting boom crossing this channel near its outer end. By this means an adequate water passage is always assured even though the surface for many feet deep may be congested with ice floes. Since the completion of this work no trouble with ice has been experienced.

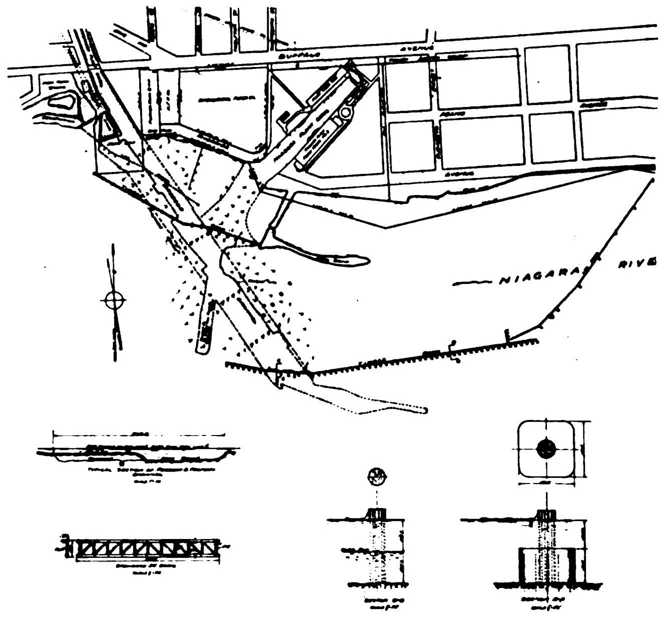

Fig. 15—Detail Map of Project Area

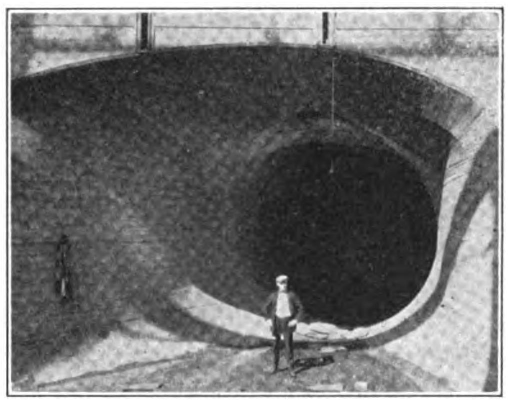

Fig. 16—Bell Mouth of One of the Penstocks

It was also necessary to deepen the Hydraulic Canal throughout its whole length to a depth of 20 ft., an increase of from 6 to 10 ft. over its former depth. This work was carried out under great diffi-

culties due to the rapid currents through the canal supplying the already existing plants.

Connected to the Canal and its terminal basin there was constructed a new forebay 176 ft. long, 74 ft. wide by 28 ft. deep. The entrances from this forebay to the three penstocks are bell mouths (Fig. 16), 28 ft. wide by 20 ft. high, and gradually taper down to true circles 15.5 ft. in diameter. The penstocks are

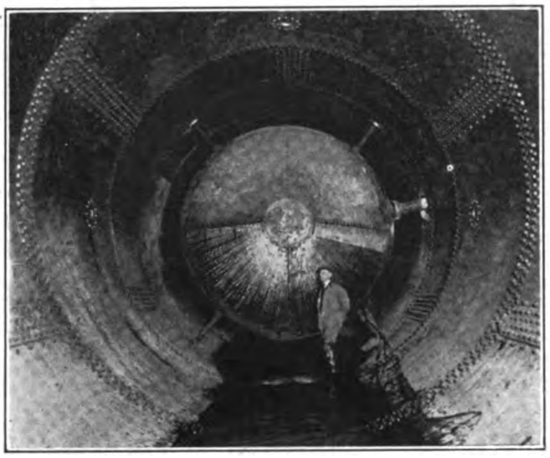

Fig. 17—Upstream End of Johnson Valve Inside of Penstock

350 ft. long, cut in solid rock, and are lined with concrete throughout their entire length. The horizontal section, in addition to having a concrete lining is also lined with boiler plate. The general arrangement is clearly indicated in the sectional view, Fig. 13.

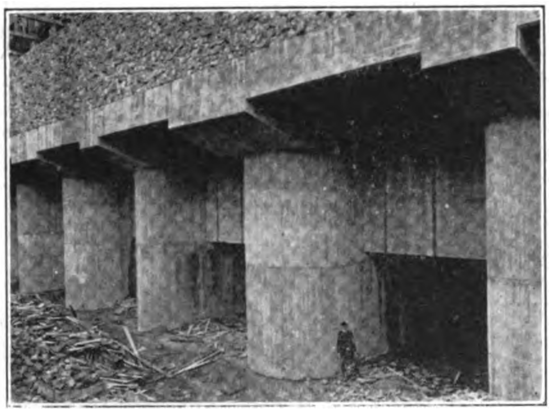

Fig. 18—Tailrace Discharge Openings through Power House Foundations Showing Concrete Supporting Piers

A plate-stee gate is provided for the intake to the penstock. This gate is only used when it is desired to unwater the penstock.

Each of the three turbine casings is connected to its penstock through a valve, (Fig. 17) hydraulically operated and electrically controlled.

The valves are of the balanced needle type, having a movable plunger sliding in an internal cylinder. Operation of the plunger is accomplished entirely by the hydraulic pressure in the penstock, no external force or pressure being required. The valve may be manually controlled locally, or electrically controlled from a switch station on a pedestal near the generating units. The rate of the valve stroke may be regulated to suit the conditions and may be set for any time up to a minimum of 30 seconds for a complete stroke in either direction. The valve is so designed that it will close automatically in case of a serious break in the wheel casing.

No provision was necessary to take care of the surges in the penstock, for being hewn through solid rock the penstock itself provides sufficient strength to withstand any force that may be set up, due to suddenly shutting down a machine.

In the design and building of the units four manufacturing companies are represented. Each turbine is of the vertical shaft, single runner, Francis type, operating under a head of 215 ft. at a speed of 150 rev.

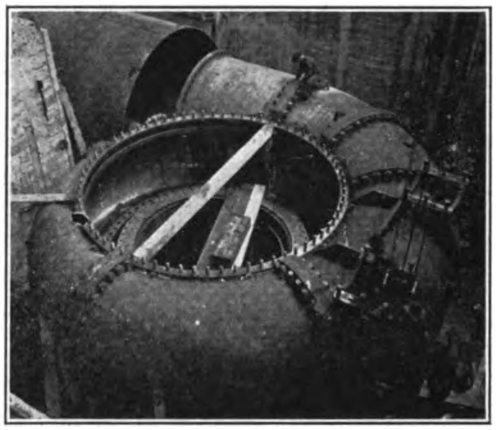

Fig. 19—One of the Cast Iron Turbine Cases

per min. and is rated at 37,500 h. p., although each has already carried more than 40,000-h. p. load. The three units were designed to develop an average working load of 100,000 h. p. Taking all frictional and other losses, from forebay to switchboard, into consideration, these units are securing over 91 per cent of the potential energy in the water used.

Each complete unit—generator, turbine and casing—weighs approximately 1000 tons and is set on a reinforced concrete slab, 11 ft. thick, 53 ft. wide and 55 ft. long, resting on reinforced concrete piers, (Fig. 18); 46 tons of reinforcing steel was used in each slab.

The casings of two of the turbines are of cast iron made in six sections and are embedded in the concrete substructure of the power house. As can be seen from Fig. 19 this casing is bolted together by flanges on the outside, consequently the inside is smooth, and is designed for a gradual acceleration of the water as it passes around the volute. The intake is 10 ft. 6 in. in diameter, and the total weight of the casing is

about 263,000 lb. The runner is of cast iron, in one piece, having a maximum diameter of 10 ft. 6 in. and a total weight of 27,000 lb. The shaft is 25 inches in diameter and is provided with a lignum-vitae guide bearing. The draft tube is of the Moody spreading type which regains the whirl component as well as the axial component of the velocity of the water leaving

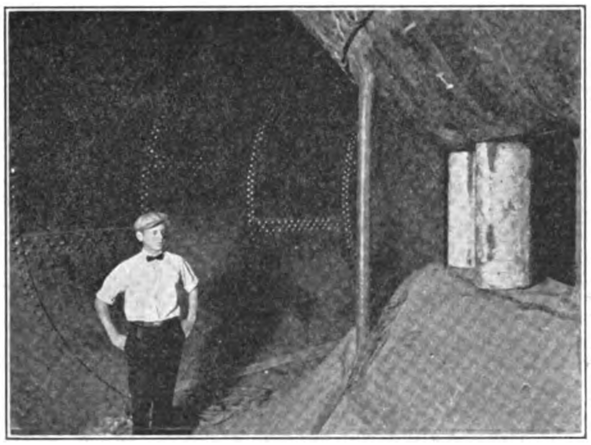

FIG. 20—INSIDE OF PLATE STEEL TURBINE CASE

the runner. This results in higher efficiency than the old type of curved draft tube, which does not regain the whirl. The spreading tube also eliminates surging and water hammer, which so often occur with curved draft tubes. These draft tubes are shown in section in Fig. 13.

A renewable ring is provided in the draft tube just below the runner, and the upper section of the draft tube is furnished with manholes for the inspection of tube and runner discharge. The total weight of each turbine is about 765,000 lb. The governors are located on the switchboard gallery with the gate-opening indicator and control stand. The regulating valve stand is on the main generator floor and is provided with plunger valves of the Johnson type. By this means the operation of changing the unit from hand to governor control is easily affected, all valves operating simultaneously.

The other turbine casing (Fig. 20) is made up of a number of conical steel plate sections riveted together, the casing being riveted to a cast-steel speed ring. The runner is of cast iron bolted to a cast-iron hub keyed to the tapered end of the shaft. A lignum-vitae guide bearing is mounted directly above the turbine. The turbine discharges into a single draft tube of the White hydraucone regainer type. Reference to Fig. 13 will make the construction clear. By the use of the hydraucone or spreading draft tube about 80 per cent of the velocity head in the discharge is recovered, whereas with the old type of curved draft tube a large proportion of this velocity head is always lost. Tests show that over 91 per cent of the total energy in the water is delivered at the generator terminals and the turbines themselves have an efficiency of 93 per cent. The fluid used in the governors is about 99 per cent water and 1 per cent oil, supplied from a central pressure system. Pressure of 115 lb. for operating the governors is maintained by static tanks at the top of the cliff. Should for any reason the fluid supply to the governors fail, they may be operated with water taken from the penstocks.

Each of the three generators is designed for a capacity of 32,500 kv-a. and generates 12,000-volt, three-phase, 25-cycle current when operating at 150 rev. per min. Although designed and built by different companies, each machine has about the same external appearance, and to this end the manufacturers cooperated so that the installation presents a uniform appearance. (Fig. 21).

As to the internal construction of the generators the engineers of the manufacturing campanies were left at liberty to follow their own ideas regarding details, the main restriction being that the electrical characteristics of the three machines must be such that they would operate satisfactorily in parallel. A box frame of usual design, 21 ft. 6 in. outside diameter, cast in sections, is used for the stator. Both ends of each phase winding are brought out so that a balance system of relay protection can be used. The windings are connected in star and the neutral grounded through a resistance of approximately 5 ohms, obtained by using a water rheostat.

The shafts are 27 inches in diameter below the rotor and are fitted with a 45 in. forged-on steel flange, for bolting to a corresponding flange of the turbine

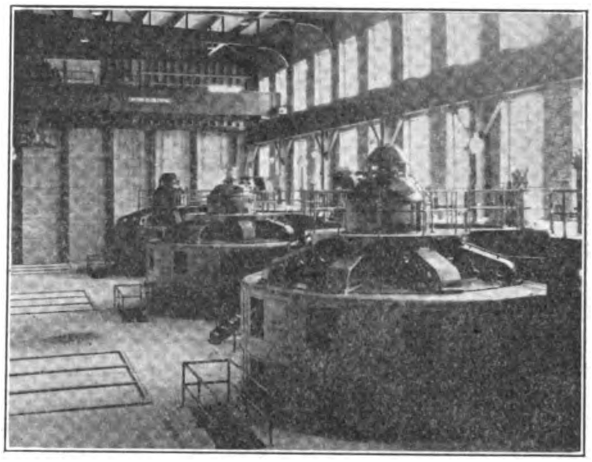

FIG. 21—INTERIOR OF STATION NO. 3 EXTENSION AFTER PLACING OF VENTILATING HOUSINGS AROUND GENERATORS

shaft. On the upper end of the shaft is the Kinsbury thrust bearing, carried on a bridge having eight radial arms. Each bearing is 49 inches outside diameter, and carries a load of approximately 470,000 lb., 100,000 lb. of which is due to the water thrust on the turbine runner. Directly under the thrust bearing is the upper guide bearing, which is 26 inches in diameter and 36 inches in length. The thrust bearing runs in a bath of oil supplied from a central

system. No water cooling coils are provided in the thrust-bearings housing, the oil being cooled and filtered in the central system.

To bring the rotating element to rest after the turbine gates have been closed, and also to prevent the rotor from turning in case of leaks through the gates, brakes are installed on the generators. These brakes are operated by compressed air, from a valve mounted on the hand-control stand located near the governor.

Ventilating air for the generators is taken into the machine from the generator room and also from the pit under the machine. The amount of air required by the different machines to carry off the heat varies from 70,000 to 90,000 cu. ft. per min. Each generator is surrounded with a steel plate housing, as indicated in Fig. 21, which connects to a duct system through a fan. In the summer months the ventilating air can be discharged outside the station. In the winter months part of it will discharge into the station and control room for heating, and the remainder will go to the ice runs. The average efficiency of the three generators at normal load and 90 per cent power factor is 98 per cent.

The leads from the generators go to an oil switch located in a terminal building on the top of the cliff above the power house, and then directly to a six-circuit transmission line carried on steel towers that runs to the Echota substation, three miles away.

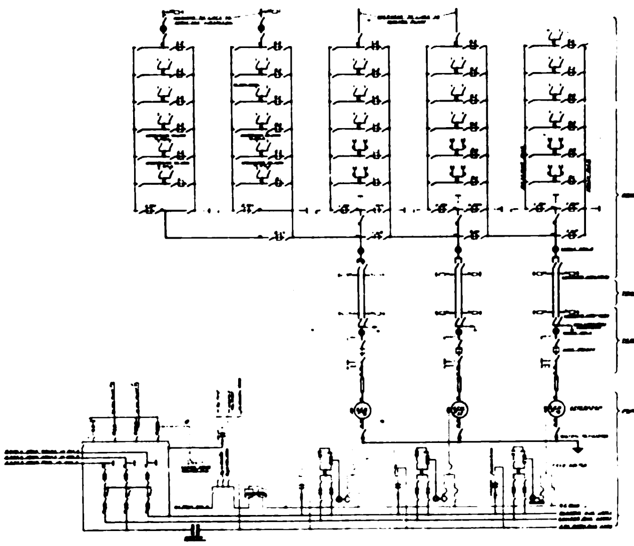

Fig. 22—One-Line Diagram of Connections, Station No. 3 Extension Development

These generator oil switches are automatically tripped by inverse time-limit relays when overloads occur outside the generators. In case of trouble within the generators the switches are opened instantaneously and the field circuit is killed by a balanced relay system of protection operated from current transformers in the generator leads differentially connected. Current transformers and inverse time-limit relays, protect each generator from overloads.

At the top of the cliff above the main generating station is the control building. On account of the simplicity of the switching arrangement, shown by the wiring diagram, Fig. 22, the control is greatly simplified, as is clearly indicated in Fig. 23. When a switch is

Fig. 23—Control Room Showing Panels for Control of 100,000 H. P. Station No. 3 Extension

opened, an annunciator on the control board shows the relay that operates it, thus indicating the source of the trouble. In each of the generators are 18 temperature indicators located at different parts of the stator windings. Six of these in each machine, that show the highest temperatures, are connected up to an indicator in the control room.

Excitation for the alternators is obtained from 2200-volt induction-motor-generator sets. Each exciter is of 225-kw. capacity, shunt-wound with interpoles, and generates 220 volts. The induction motors can be supplied from three separate and distinct sources, any one of which can be connected to a duplicate set of busses, and the 2200-volt induction motors, driving the exciters, connected to these busses through selector oil switches. An emergency source of excitation may be obtained from direct-current busbars in Station No. 3. This circuit is connected through a field rheostat to a busbar, to which the field coils of any one of the alternators may be connected in case of failure of its motor-generator exciter.

In laying out the station, effort was made to divide the electrical and mechanical operating functions. Electrical operation is centered in the control room and the mechanical in the station. How successful havy been the efforts to simplify operation is evidenced by the fact that a station of a normal operating capacite of 100,000 kw. is being operated by three men on a shift. The general external appearance of this station and its relation to Station No. 3 are shown in Fig. 24.

Transmission Line to Echota

The transmission line has a length of 16,000 ft. and runs from the terminal building up the canal to the river, thence following the bank past the plant of the old Niagara Falls Power Company (now known as the

Niagara Plant) and finally turning away from the river again at Echota to connect with the Echota substation.

The solution of the transmission problem was greatly facilitated by the consolidation of the two power companies, as land for the location of the line for the

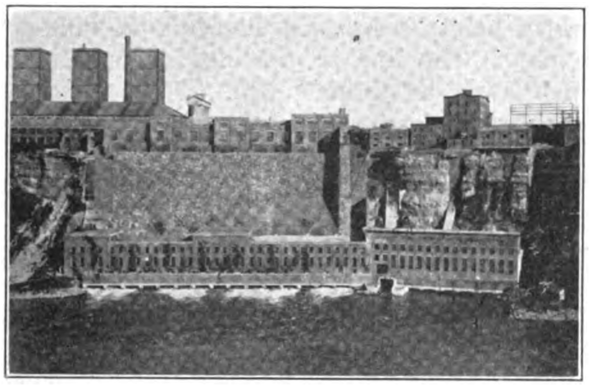

FIG. 24—VIEW OF STATION NO. 3 AND EXTENSION FROM CANADIAN SIDE OF NIAGARA RIVER

greater part of its length was already in possession of one or the other of them. For a distance of approximately 4000 ft. through the heart of the city, however, it was necessary to make use of the property already occupied by the hydraulic canal. This was accomplished by means of steel cantilevers anchored into massive concrete foundations on one bank of the canal, upon which were erected the six-circuit transmission towers.

For the greater part of the distance it was found necessary for only the narrow bases of the towers to be placed over the canal right-of-way, easement being obtained from abutting property owners for the

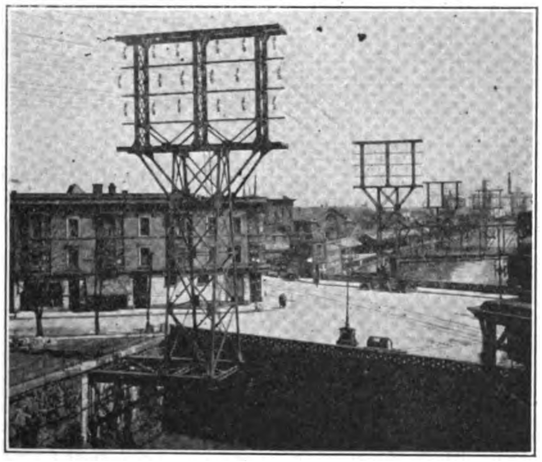

FIG. 25—TRANSMISSION LINE CROSSING STREET INTERSECTION SHOWING LONG CANTILEVER FOUNDATIONS

overhanging portion of the construction. At the large bridge spanning the canal at the junction of Third and Niagara Streets, however, this was not possible, and it was necessary to place two towers entirely over the canal. This was accomplished by means of long cantilevers extra heavily braced, as shown in Fig. 25.

The main horizontal members of this structure are composed of two 30-in. I beams, each 60 ft. long,

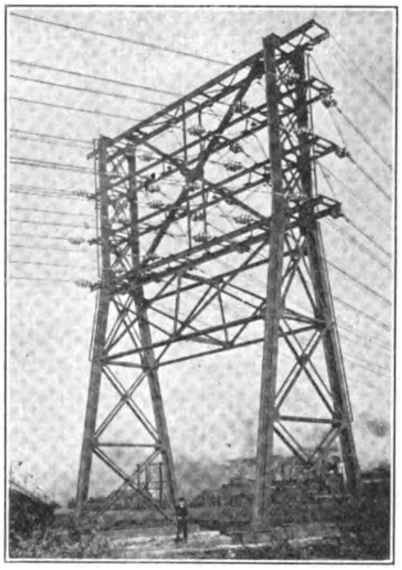

FIG. 26—PORTAL ANCHOR TOWER

placed side by side. Thirty feet of these beams is buried in the massive concrete foundation, the other 30 ft. projecting out over the canal. In these structures the center line of the towers is 25 ft. from the face of the canal wall. A heavy brace was added to these special structures to give stability and rigidity, although not needed for strength. In the case of the short cantilevers the brace was omitted.

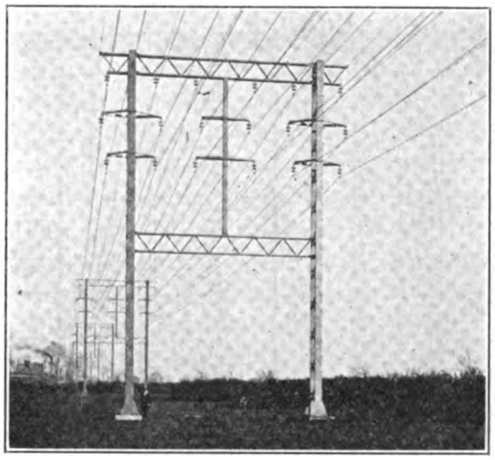

FIG. 27—FLEXIBLE PORTAL TOWER

In addition to the special narrow-base towers used on the canal section, the local conditions called for the use of several other types of structure, two of which are shown in Figs. 26 and 27. The portal type of construction was used for the section along the river bank where the line is built over a future street.

The line comprises six three-phase circuits, each

consisting of 500,000-cir. mil stranded medium hard-drawn copper. At present two circuits are used for each 32,500-kv-a. unit at 12,000 volts, but clearances are provided for 66,000 volts.

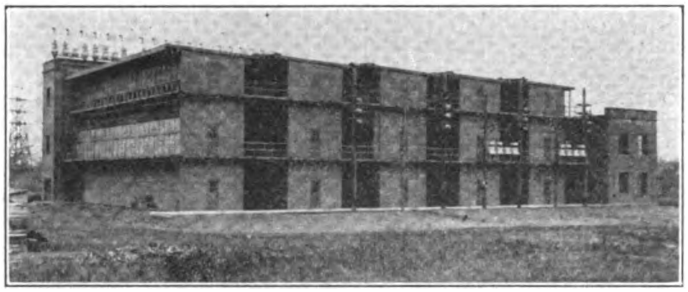

FIG. 28—ECHOTA DISTRIBUTING STATION SHOWING OUTGOING OVERHEAD LINES
Most of the feeders leave the station underground

Owing to the fact that this line passes through the business portion of a busy city, special precautions were taken to guard against failure. Each conductor is strung for a maximum tension under worst conditions of wind and ice of 6000 pounds. At strain towers double-strain insulators are used. Short spans, not exceeding 350 ft., were used as a further contribution toward safety and stability.

The line is insulated with substantial spider-type suspension insulators, two units being used in suspension strings and three in strain. On the canal section, because of the peculiarities of the right-of-way, it was impossible to avoid a number of small angles, at which points suspension strings with hold-downs were used. The line is protected against lightning by five overhead ground wires, $\frac{3}{8}$-in. copper-clad wire being used for this purpose.

ECHOTA DISTRIBUTING STATION

The Echota substation is intended to serve three functions—(1) to subdivide and distribute the power from the new plant, (2) to serve as a clearing house for the output of the five generating stations, aggregating 400,000 h. p., and (3) to act as a future step-down transformer station.

Inasmuch as the primary function of this station is to distribute the power of the new plant, it was decided to preserve the unit arrangement in its construction. The station was accordingly laid out in units of a nominal capacity of 32,500 kv-a. Five of these units were constructed, three for the new plant and two for interconnection with other generating stations. A

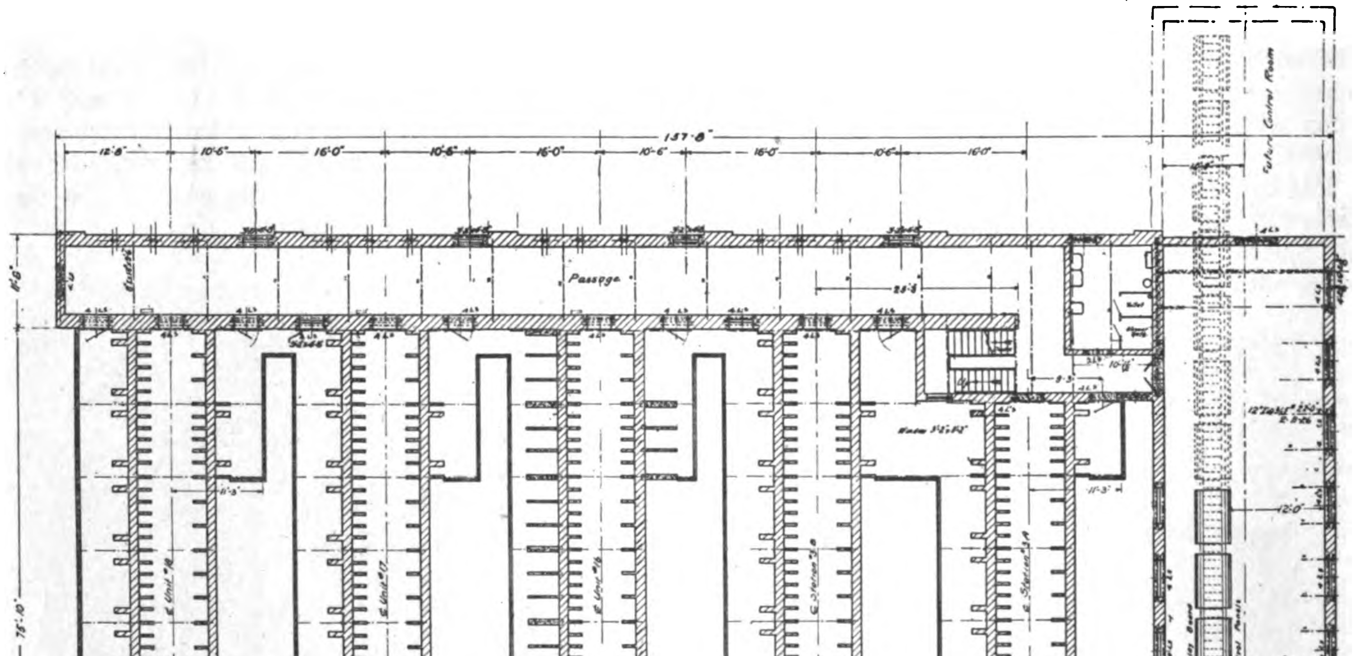

FIG. 29—PLAN OF ECHOTA DISTRIBUTING STATION—SECOND FLOOR

control building containing the switchboard apparatus was also erected. The general wiring diagram, Fig. 22, shows the arrangement of the main circuits; the physical layout of the structure is similar to that of the diagram. The general scheme is that of a main tie bus running lengthwise of the building with the unit lateral busses joining it at right angles.

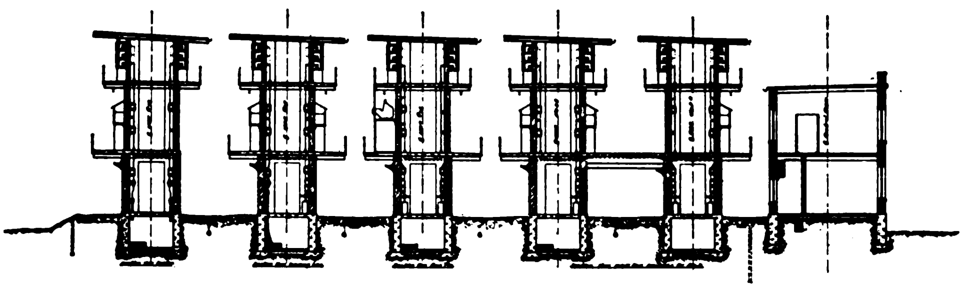

FIG. 30—LONGITUDINAL SECTION OF ECHOTA DISTRIBUTING STATION—LOOKING WEST

The five units or bays and the control building are connected at one end by a narrow building or passageway which contains the incoming line protective equipment and serves as a distributor for the control wiring, piping, etc., and as a means of access between the control building and the several unit bays. The main operating portion of the station is concentrated on the second floor which contains the oil switches with their disconnecting apparatus and the control room. Under each of the unit bays is a subway for distribution of cables. This connects at each end with longitudinal subways.

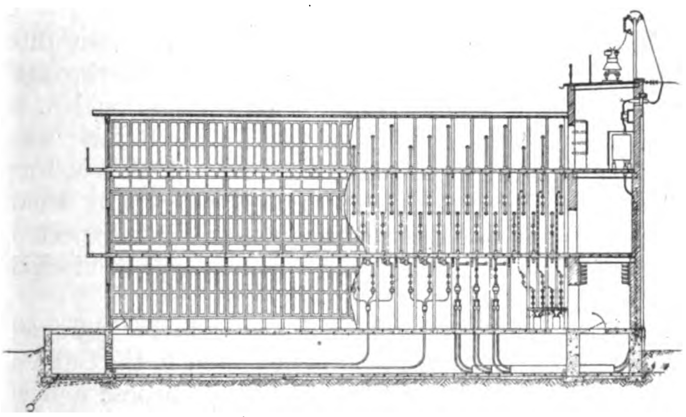

FIG. 31—CROSS-SECTION OF BUS STRUCTURE THROUGH ONE BAY OF DISTRIBUTING STATION—LOOKING SOUTH

A radical departure from the usual station construction is the placing of all oil circuit breakers on the outside of the building walls; in other words, the main bus and switch structure walls are utilized as the walls of the building, all high-tension connections being upon the inside, where they are thoroughly housed and protected against the elements, and the oil switches upon the outside, where explosions and oil fires can do a minimum of damage. Galleries are provided on the outside for access to the oil switches which are protected from the weather by suitable housings.

Each incoming line, after passing through a set of choke coils for lightning protection, divides, one side going through an oil circuit breaker to the main bus, the other side through a similar breaker to the unit reserve bus. In each bay provision is made for six outgoing feeders. Each of these connects to the main bus through an oil circuit breaker and to the reserve bus through disconnecting switches. The function of the reserve bus is twofold—(1) It serves as a true reserve bus from which all feeders can be supplied temporarily through the reserve-bus switch. (2) The reserve-bus switch serves as a substitute switch for any individual feeder switch which may be out of service. In this manner duplication of the switching facilities is obtained without duplication of oil switches on each feeder. Provision is made for the installation of reactors between bays, and these will be installed as soon as they are required.

Owing to the great importance of this station in the general scheme of distribution, both present and future, it was determined to insure the greatest possible degree of reliability in the oil switches. Accordingly both of the chief manufacturers were asked for a recommendation on this basis, resulting in the proposal of two radically different types of oil switches, namely type *C O*-2 and type *H*-9. Owing to the absence of operating experience with these switches, it was found impossible to establish definitely the superiority of either one over the other, and it was decided so to construct the station that either one could be used. This was accomplished by slight modifications in the standard assembly of both types, and it was decided to install at the start a number of each type in order that actual operating experience might be had with both.

The doors covering the disconnecting switches of each circuit breaker are all operated together so that it is impossible for an operator to obtain accidental access to a disconnect of an adjacent circuit breaker. These doors are mechanically interlocked with the circuit breaker so that they cannot be opened until the corresponding oil switch is in the open position.

The switchboards consist of vertical panels and are divided into five sections corresponding with the five main bays, in addition to a house-service section. Back to back with the control boards, with a 4-ft. aisle between them, are the relay and terminal boards. Each instrument and relay is provided with a complete set of calibrating link terminals mounted upon small panels on the rear of the main panels.

The vertical wiring on the back of the switchboards is carried in troughs 3½ in. wide, made up of two ¾ in. angle sides with asbestos board back and removable

sheet-metal covers. The advantages of this system of wiring are safety, accessibility, neatness, ease of installation and flexibility.

At their point of departure from the board, all control wires pass through terminal links and are then carried in steel pans or troughs mounted one above another on brackets fastened to the wall of the building. By this construction the control wiring is made accessible practically throughout its entire length, and at the same time an enormous amount of conduit work is avoided.

For the operation of the control circuits there are provided two 14-kw. motor generator sets and a 120-ampere-hour, 220-volt storage battery.

The incoming lines from the new generating station are each equipped with overload, ground and reverse-power relays. These relays are arranged to trip both the main and reserve-bus circuit breakers. The bus-tie switch is equipped with overload relays. Feeder switches are relayed in two different ways, according to the nature of the feeder supplied. In certain cases where a feeder consists of four parallel cables, split-conductor protection is provided between the two pairs of cables by means of suitably connected current transformers and low-current relays. In other cases ground relays are installed, connected in the current transformer neutrals. Overload relays are also installed on all feeders. All relays are of the induction type, the five-ampere size being used for overload and the one-ampere size for differential and ground protection.

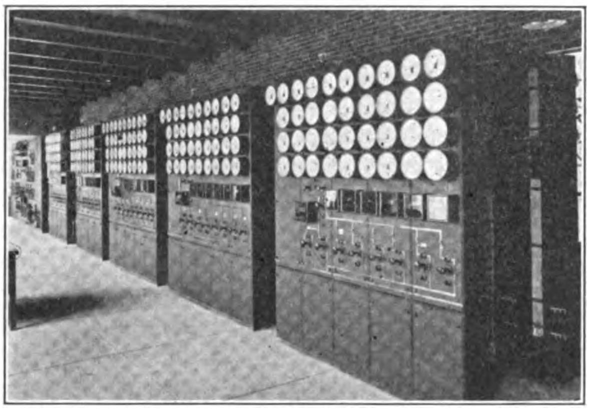

Fig. 32—Switchboard at Echota Substation

A somewhat unusual feature in connection with the relay system is the installation of annunciators on the switchboard with the drops connected in series with the tripping circuits of the various relays. By this means it is possible to know at once upon the tripping out of a circuit breaker just which relay was responsible. This immediately gives an indication of the nature and in certain cases of the location of the trouble. It also furnishes the means of keeping tabs on the operation of the relays. Although the station has been in operation only a few months, the value of this feature has already been amply demonstrated.

Further Development Authorized by Federal License

The completion in 1920 of Station No. 3 Extension for three 37,500-h. p. units provides for the utilization of the entire amount of water, 20,000 cu. ft. per sec., which is available under the existing treaty. But there has been, and with the return of normal industrial conditions there will be again, a demand for additional power.

Since, by Act of Congress creating the Federal Power Commission the U. S. Government assumed control of the Niagara River situation it became necessary that the Commission's approval be obtained for any further development of power. As no further water is at present available the only source of additional power is the use of some of the present water under increased head. Naturally, the least efficient of the existing plants would be the one first selected for obsolesence, which in this case is the "Niagara" plant, which, operating under an effective head of 140 ft. obtains but 12.1 h. p. per cu. ft. per sec. as compared to 21 h. p. per cu. ft. per sec. in the Station No. 3 Extension.

The economic reasons for the plan adopted for the re-development of this water have been given above and the Company is now proceeding under License from the Federal Power Commission with the construction authorized.

The power will be developed in a further extension to Station No. 3 along similar lines to those followed in the already completed extension.

The water will be brought from Port Day through a 32-ft. horseshoe-shaped tunnel at a depth of about 100 ft. below the surface of the ground. From this tunnel the water will be taken to the penstocks through a forebay similar to that provided for Station No. 3 Extension. The construction of this tunnel was started, with fitting ceremonies, on April 25th of this year, and the work is now proceeding rapidly from both ends and two intermediate shafts. It is expected that the first unit of this development will be started on or before May 1st, 1923.

A portion of the additional power to be obtained from this development will be delivered to the Buffalo General Electric Company. For this purpose a new 66,000-volt transmission line is now under construction from the Echota Station to the vicinity of the steam station of that Company which is located on the Niagara River about a mile below the Buffalo City Line. This new line will consist of two circuits of 500,000-cir. mil copper and will be capable of transmitting upwards of 100,000 h. p. to Buffalo. This line, unlike its predecessors, will take a direct route, first crossing the East arm of the Niagara River from the mainland to Grand Island, thence running straight across the island and recrossing the river to the mainland again between Buffalo and Tonawanda, whence it will extend to its terminus by the shortest available route. At the lower crossing the river is about 4000

ft. wide and the crossing will be made in two long spans of about 1600 ft. and two shorter anchor spans, with channel clearances of 75 ft. At the upper crossing the river is narrower and the crossing will be made in a single long span of about 1800 ft. with 115 ft. channel clearance.

Niagara Power in American Industry

In a condition of society where each man's livelihood depends upon his own unaided efforts, the state of civilization must necessarily be low and the majority of the population in poverty and misery. Conversely, the state of civilization will be the most advanced and the general well-being the greatest, where the ratio of usefully employed power to population is the highest. It follows therefore, that the ultimate state of civilization will depend upon the efficiency with which the country's *inexhaustible* power resources are made to minister to the needs of man.

It is profitable, therefore, to examine the uses to which our power resources are to be put, and particularly is it profitable to do this in the case of Niagara, the greatest single source of water power in North America. Here is a power stupendous in magnitude, absolutely continuous in character, easily developed, at a construction cost so relatively low that the electric energy cost to customers is the very lowest, and located in the midst of a large industrial population with abundant labor, adequate transportation, and a near-by market immediately available. Compare this with the large western powers, located in almost inaccessible fastnesses of the mountains and far removed from all those other factors necessary to industry, namely, labor, transportation, raw materials and market. The contrast is striking, and should rightly give us pause to consider the corresponding contrasts in the proper utilization of these diverse developments. In general, the western water power must be transmitted great distances and utilized in those applications where the value of the service will warrant the cost of such transmission. Not so, however, Niagara. Here Industry can come to the very doors of the power plants and obtain absolutely continuous power with no added expense for transmission.

It would seem, therefore, that Niagara was intended by Nature for application to these primary industries requiring continuous power at low cost, especially electrochemical and electrometallurgical processes, producing essential raw materials for use in secondary industries engaged in the manufacture of finished or semi-finished products. This is the destiny of Niagara. Not primarily in lighting the lamps nor in turning the wheels of industry is to be found the ultimate outlet for Niagara's steady energy, but in the production of the necessary *materials* of industry which can be produced in no other way.

Such has been, in fact, the principal use to which Niagara power has been put, and it is not entirely coincidence that the great industrial growth of America has been contemporaneous with that of the development of Niagara. To what extent, for instance, the development of the automobile industry has been dependent on Niagara power, we do not know exactly, but it has been estimated that the withdrawal from this industry of only three of Niagara's products, namely, ferroalloys, artificial abrasives, and aluminum, would both increase car weights and decrease production by about 80 per cent. What is true of the automobile industry is also true to a very great extent of all of our industries. Niagara might today be rightly named the "Mother of American Industry."

This conception of Niagara's destiny, however, has not always obtained. Before the discovery of these products, or of ways for their manufacture and use, Niagara's energy was thought of entirely in terms of turning wheels and illuminated houses and streets. So some of the earlier developments were predicated upon transmission but with the gradual unfolding of her peculiar genius, it has slowly come to be recognized that, like all good mothers, her most important duty is at home. Immutable economic laws will dictate that at home all her energies must ultimately be expended, "mothering" America's industries, but for some time to come there may not be a sufficient outlet for her energy in this direction.

During the three decades since the birth of hydroelectric development, we have been catching up with the demand and the development has been correspondingly rapid. As the capacity of America to absorb the products of those industries to which Niagara has given birth gradually becomes saturated, the rate of development will naturally become slower and more commensurate with the growth of population of the whole country, unless a new and broader outlet for her energies is developed. That those energies should be developed to the full, and that as soon as may be, is not to be questioned. Once it has been determined, as has now been done by the Federal Engineers, as to how much of Niagara's potential power may be put to work, there should be no delay. Every pound of water that can be spared but is permitted to pass without doing work when there is work to be done, means the unnecessary destruction of just so much of our limited coal supplies. Therefore, pending the time when all of Niagara's energy is needed at home for use in primary industries, such part as is not so needed should be employed, elsewhere if necessary, in secondary industries or in ministering to the comfort and convenience of the people in their homes. This is legitimate and feasible, but its consummation should be undertaken with caution.

It must be borne in mind that the attainment of our highest good must ultimately demand the most efficient use of this power. Nor is efficiency here meant in any narrow sense, but in the broadest sense of the greatest good to the greatest number. Within the next few

years we shall undoubtedly see great superpower transmission lines reaching out hundreds of miles from Niagara, putting her surplus power to work, but as the years roll on and the growth of our population creates

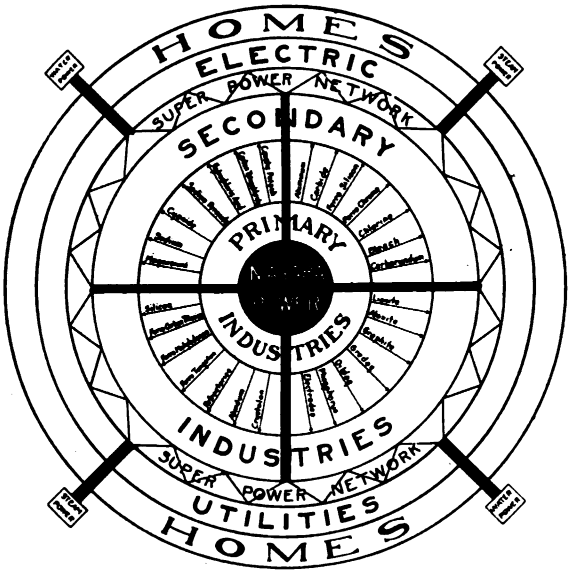

FIG. 33—NIAGARA POWER IN AMERICAN INDUSTRY

increasing demands for the peculiar products of Niagara's particular genius, we shall see this energy distribution gradually being drawn in. And creeping after it we shall see great steam plants slowly but steadily approaching Niagara, replacing in the homes and secondary industries, that energy which, as times goes on, can less and less be spared from the "mothering" home industries of Niagara.

So we shall finally reach the ultimate condition wherein Niagara shall become the center of a great industrial community. (See Fig. 33.) In an inner ring around the Niagara power nucleus will be the great primary industries producing the peculiar raw materials for which this power is necessary and which are themselves in their turn necessary to others. And surrounding this ring will be another and a wider ring of secondary industries obtaining their specialized raw materials and certain of their tools from the primary industries of Niagara and their power from a superpower network fed from those inherently variable power sources, both water and coal, such as are adapted to their needs. But connecting this superpower network with Niagara's power will also be transmission lines, and as the tide of industry ebbs and flows so will also ebb and flow the tide of power over these lines. Always, when the need demands, Niagara's power will be drawn back within the inner ring to do its own peculiar work which no other power can do, but when in the swing and surge of industry the home demand is lightened, out will go Niagara's power again over the interconnecting transmission lines to the beneficent work of saving coal by its use in the secondary industries and utilities. In this manner will Niagara's steady flow be kept continuously at work.

A 140,000-H. P. HYDROELECTRIC PROJECT FOR FORMOSA

The Bureau of Foreign and Domestic Commerce has received from Consul Henry B. Hitchcock, Taihoku, Taiwan (Formosa), a copy of the specifications and drawings for the mechanical and electrical equipment of the Jitsugetsutan (Lake Candidius) hydroelectric project to be constructed by the Taiwan Electric Power Co., which has been forwarded to the bureau's New York office, 734 Customhouse, in order that it may be more readily consulted by interested persons. (Reference should be made to File No. 29632.)

The generating station is to consist of six 20,000-kilowatt alternating-current generator units directly coupled with Pelton type waterwheels operating under a mean actual head of about 1370 feet. In addition to the main waterwheels and generators, the specifications also call for water-driven exciter units, penstocks, governors, valves, eighteen 7400-kv-a. step-up transformers, switchboard, and switching equipment, and other auxiliary apparatus, including a traveling crane. For the two substations there will be required twenty-one 7000-kv-a. step-down transformers, three synchronous condensers, and the switching and other auxiliary equipment in connection therewith.—*Commerce Reports.*

ELECTRIFICATION IN BRAZIL

Traction Improvements in Pernambuco. According to telegrams from Pernambuco, says *Commerce Reports*, the tramway company of that city has just installed a large up-to-date turbine with a capacity of 3000 kilowatts, which will double the capacity of the old plant. Installations of substations at Gracas were also inaugurated for furnishing light to the districts of Torres, Zumby, Casa Amarella, Pranamerin Espinheiro, Encruzilhada, and Capunga.

Electrification of the Paulista Railway. It is understood that the initial order which has been placed in the United States by American contractors for the electrification of the Paulista Railway comprises material sufficient to take care of the first 45 kilometers, the Jundiahy to Campinas section. Two of the four engines to be furnished by another American company are passenger locomotives of 2000 horse power weighing 121 tons each, one being capable of a velocity of 104 kilometers on a 1.60 meter gage. The remaining two are freight engines of 1500 horse power, weighing 87 tons each, with a speed of 64 kilometers per hour. An aerial circuit of 3000 volts continuous current will furnish the motor force with transmission to the trolleys. The entire electrification when completed will cover about 160 kilometers.

Technical Committee Annual Reports, 1920-1921

MINES COMMITTEE

To the Board of Directors:

THE Chairman of the Mines Committee of the A. I. E. E. for 1920-21 has had the honor of being also the Chairman of a similar committee, the Mine Equipment Committee, of the A. I. M. E. It has been the endeavor during the past year to have the two Committees work together since the object of these Committees is very much the same.

A meeting of the Committees was held in Chicago in November of 1920 at which time it was decided that one of the best methods to work together would be to foster joint meetings of the local sections of the A. I. E. E. and A. I. M. E. By these meetings, it was hoped that various engineers in the local sections interested in mining subjects could be brought together and not only become better acquainted, but could be greatly benefited by the interchange of ideas and by the discussion of papers presented on mining subjects.

It was also decided that both Committees should encourage the writing of papers on mining subjects to be presented, either at local section meetings or at the National meetings.

It was also decided that these Committees should work in conjunction with the American Mining Congress and the American Engineering Standards Committee in developing standard practises for both coal and metal mines in the United States.

The first combined meeting of the local sections was held in Pittsburgh on January 18, 1921, the meeting being held at the Bureau of Mines. An afternoon technical session was held at which a paper was presented by F. W. C. Bailey on the subject of "Power Rates for Coal Mines." This paper was well received and produced an active discussion. Following the afternoon meeting, a visit was made through the Bureau of Mines Buildings, after which dinner was served at the same place. The evening session was held in the auditorium of the Bureau of Mines and a paper was presented on "Gathering in Coal Mines" by R. Kingsland of the Consolidation Coal Company of Fairmont, W. Va. Both afternoon and evening papers have been submitted to the Publication Committee of the A. I E. E. for publication in the JOURNAL.

A second combined meeting has been arranged to take place in Chicago on April 25th. This meeting will be participated in by the Electrical Section of the Western Society of Engineers, the Mining Section of the Western Society of Engineers, the Iron & Steel Electrical Engineers of Chicago, and the Chicago Section of the A. I. E. E. Two papers will be presented as follows: "Diversity Factor of Coal Mining Loads" by Carl Lee, Electrical Engineer, Peabody Coal Company; and "Power Distribution Systems for Coal Mines," by W. C. Adams, Allen & Garcia Company.

The Philadelphia Section has agreed to have a combined meeting, but wishes to put it off until the Fall of this year as it has recently held two combined meetings with the Engineers Club of Philadelphia and does not wish to have another combined meeting in the near future.

It is hoped during the present year to have additional combined meetings in some of the Western States.

PROGRESS OF ELECTRIFICATION OF MINES

Until recently, the coal mines of the United States have been particularly active and the price of coal has been such that most mining companies have had a fairly profitable season. This has enabled a great many mines to establish improvements in the way of electrifications that they had been looking forward to for some time. A few years ago, the central stations were having a very difficult time to persuade the coal mining companies that they could sell them power cheaper than the coal mining companies could produce it themselves. Recently, the conditions have been somewhat reversed and in many cases the central stations have found it necessary to refuse coal mine loads on account of having no surplus capacity. In the large majority of cases, it is not difficult to show a coal mining company that it can operate its mines more economically from purchased power than from its own power plant.

Isolated power plants are being installed in some cases where central station power is not available, and also where the operator feels that central station power is not as reliable as his own plant would be. This is particularly true where the coal mining plant is throwing away fairly high grade waste coal and where a standby steam plant is kept in operation to take care of operating the auxiliary hoist and fan in the case of power failure. The tendency in isolated plants is to install geared turbines up to a capacity of 500 kw., and above this capacity the direct connected a-c. turbine. The turbine installation makes a much simpler plant to operate when compared to the old engine-type stations and turbine plants have records of long continued operation with practically no interruptions and a very low cost of operation.

The synchronous converter is becoming more popular each year for mine service. This is due largely to the improvement in converter design which makes this apparatus as strong and simple to operate as the motor-generator set, with the advantage that it takes up less room and is much more efficient.

The most important development during the last year has been that of the automatic substation for

mine service. One of these plants has been in successful operation for several months and several more are being built. The automatic substation has the advantage that it performs all of the operations that are necessary in a substation at the proper time and much better than could be accomplished by manual operation. The automatic equipment makes no false moves and in case of trouble of any kind, acts on the safe side and shuts down the station if necessary. It is felt that in the future, the automatic substation will play a very prominent part in mine installations.

The electric hoist is rapidly replacing the steam hoist to such an extent that a steam hoist is rarely installed in a new mine. The large majority of hoists for coal mines is of the alternating current type using a wound rotor induction motor with the magnetic type of control. Recent improvements in the control and safety devices make the electric hoist practically fool-proof and serious accidents are of very rare occurrence. A few installations have been made using the Ward Leonard system of control and flywheel motor-generator set. The Ward Leonard control is necessary where very fast hoisting cycles are required and the flywheel is necessary where the customer is penalized for momentary peaks.

The past year has seen a continuation of the develoment and application of magnetic control to mine locomotives. The demand for the individual capacity of mine locomotives has been increasing until it becomes very difficult to supply a drum type controller for 250-volt service. The magnetic type of control is a very satisfactory solution for this problem, and a number of such locomotives have been recently installed. The large unwieldy drum controller is replaced by a small master controller which takes away a considerable element of danger from the motorman's position. The main controller, consisting of magnetic contactors and reversers, can be distributed back in the locomotive, preferably suspended from the underside of hinged covers which enables the equipment to be inspected readily and repaired. The use of magnetic control has greatly simplified tandem operation. With drum-type controllers, it is necessary to mount a large four-motor controller on the primary unit, a two-motor controller on the secondary unit, and the two units connected together by a large number of heavy power cables, when tandem operation is required. With magnetic control, the two units are identical and the only connection between the units required is one power cable and a control cable consisting of nine control wires. The advent of magnetic control makes it necessary for the mining companies utilizing it to furnish better voltage regulation for the mine circuits which in turn will save considerable power loss and also keep down repairs on mining equipment, which repairs in the past have been largely due to poor voltage regulation.

A number of improvements and new features has been added to the construction of mine locomotives during the past year. Of these, the most important are the substitution of the leaf type spring for the helical type of spring, the installation of the end-thrust type journal box, the use of equalizers on two-axle locomotives, the application of detachable rims to locomotive wheels and the more general application of dynamic braking on mine locomotives. The value of these various improvements can only be determined after a thorough trying out.

Metal Mining Industry

The metal mining industry has been particularly quiet during the last year due to the low value of practically all metals excepting iron and steel. In the copper mining industry, one of the recent improvements has been the installation of a motor-driven turbo blower to replace a Root type for such service as air for cupolas, converters and flotation cells. These blowers require high-speed synchronous motors which are of the turbo type.

The metal mines have been doing a little work toward revamping their plants and installing new equipment, but this, of course, has been greatly hampered by the poor market conditions.

Shovels and Drag Lines

Electric power is gradually replacing steam on shovels and drag lines where electric power is available. There are at present, two systems being used, one the a-c. in which wound rotor induction motors are used to operate the various parts of the shovels and drag lines. The other system is to use d-c. mill-type motors receiving power from a synchronous motor-generator set. The motors are operated by rheostatic control. A recent development is being watched closely by all engineers interested in the handling of shovels and drag lines. This consists of d-c. motors on the shovels receiving power from the synchronous motor-generator set with a separate generator for each motor. Ward Leonard control is used and the advantage of the system claimed is that all rheostatic losses are eliminated and the momentary peaks are kept off the power system. It is hoped that during the next few months sufficient data will be obtained to determine the feasibility of this system and its economy when compared with the other two systems.

Car Dumper

During the past year, some very important installations of car dumpers have been made at the Atlantic ports. These car dumpers are increasing in size from year to year and there has recently been placed in operation at Baltimore the largest car dumper as yet constructed. This car dumper requires four of the largest mill-type d-c. motors built on the cradle hoist, all operated from one master controller. It is felt that if these car dumpers increase further in size,

it will be necessary to utilize the Ward Leonard control system.

A very interesting installation of grain car dumpers has been placed in operation during the past year at Baltimore. This car dumper takes care of unloading box cars filled with grain, with practically no manual labor. All motions are interlocked, so that it is practically impossible for the operator to make the wrong move and cause any considerable damage.

Ore and Coal Bridges

There has been little change in the type of equipment for ore bridges during the past year, but in regard to coal bridges, the largest one ever built has been installed and placed in operation by the American Bridge Company at the By-Product Coke Plant of the United States Steel Corporation at Clairton, Pa. This bridge is by far the largest ever constructed and it is expected to take care of a very large tonnage of coal from barges in the river to storage piles, in order to insure a steady supply of coal to the coke ovens at Clairton, which is the largest by-product coke oven plant in the world.

By-Product Coke Oven

During the past year, an advance has been made in the design of locomotives for quenching service in and about by-product coke ovens. The latest type of locomotive is equipped with electropneumatic control having not only automatic acceleration, but also the ability to operate on any notch. These locomotives weigh about 25 tons each and have a number of new features in regard to mechanical arrangement of parts that are quite an improvement over the past type of construction for quenching locomotives.

The coke-loading locomotives at the Clairton plant are of the combination type, using remote control while the coke train is being loaded. These locomotives have been operating very successfully during their second year, and have affected a large saving over the older scheme of using steam locomotives, or the cable haul. It is felt that in the future there will be a considerable call for the remote control of locomotives and cars, not only around coke plants, but also where large amounts of material are to be handled over fairly great distances.

Graham Bright, *Chairman.*

INSTRUMENTS AND MEASUREMENTS COMMITTEE

To the Board of Directors:

The Instruments and Measurements Committee submits the following report containing a brief statement of its own activities, brief mention of significant papers issued during the year and as comprehensive a statement, as can be briefly condensed into a report of this character, of the progress in the electrical field covered by its title.

The committee arranged for a number of papers for presentation at the Midwinter Convention in February and had a session assigned to it. The papers presented at the session are as listed below:

Regulation of Frequency for Measurement Purposes, by B. H. Smith.

Measurement of Relative Eddy Current Losses in Stranded Cables, by J. A. Cook.

An Electromagnetic Device for Rapid Schedule Harmonic Analysis of Complex Waves, by F. S. Dellenbaugh, Jr.

The Limitations of the Stopwatch as a Precision Instrument, by A. L. Ellis.

The paper by Mr. A. L. Ellis, listed above should be considered as related to the paper by Mr. H. B. Brooks which was presented last year under the title of the Accuracy of Commercial Electrical Measurements. This paper by Mr. H. B. Brooks, it was hoped would contain an analysis of the characteristics and limitations of the stopwatch, as well as the purely electrical instruments. This could not be included, however, and it was felt by the committee this year that it would be desirable to have such a paper on record. The paper was, therefore, prepared by Mr. A. L. Ellis and serves very well indeed to supplement or complete the very thorough paper presented the year before by Mr. H. B. Brooks.

In addition to the papers referred to above, other papers or articles are listed below which seem of sufficient significance and value to include in this brief report. It is not intended or even possible to make a complete bibliography of all papers or articles which may have appeared during the past year, relating to the general subject of instruments and measurements, but as stated above the following brief mention seems of value in this report:

The Corona Voltmeter and the Electric Strength of Air, by Whitehead and Isshiki, in the Journal, A. I. E. E. for May 1920. The proposed increase of transmission line voltages makes the measurement of crest voltage of increasing importance. In this paper Dr. Whitehead describes refinements in the corona voltmeter and a modification of the previously accepted law of corona.

"New Current Balance for Calibration Work," by Otto A. Knopp, *Electrical World,* Vol. 75, May, 1920. This apparatus makes it possible to obtain a large number of standard values of current from a single value calibrated by independent means. It is especially suitable for central station use in the calibration of a-c. ammeters.

Portable Oscillograph, by J. W. Legg, Journal, A. I. E. E., July, 1920. The oscillograph in its previous forms is a valuable instrument, but is not well suited to field work. The form described by Mr. Legg replaces the arc lamp with a tungsten lamp operated at very high efficiency, and excites the galvanometer magnets from a storage battery. A number of ingenious features are included in order to control exposures.

A Dynamometrical Comparator, by Edy Velander,

JOURNAL, A. I. E. E., July, 1920. The accurate measurement of small alternating currents presents considerable difficulty. This comparator, in connection with a d-c. potentiometer, is stated to give accurate measurements of currents from 5 to 50 milliamperes, at frequencies up to 2000 cycles.

"Permanent Magnets in Theory and Practise," by S. Evershed, *Journal*, Inst. Elec. Eng. (London), Sept., 1920. This paper is primarily of value to the designer and maker of electrical instruments and meters.

"Magnet Steel," by Honda and Saito, *Electrician*, Dec. 17, 1920. This paper gives the properties of a remarkable steel for permanent magnets, having a very large coercive force and intensity of residual magnetization.

The method of making large ammeter shunts which was mentioned in a paper before the Institute in February, 1920, has been used by A. B. Field in England, who gives particulars in a paper in the *Journal* Inst. Elec. Eng. for August, 1920. This paper and its discussion are particularly valuable in view of the increasing size of totalizing shunts used to measure the direct current output of synchronous converters or the total direct-current output of substations.

Wattmeters have been made on the electrodynamic, electrostatic, and electrothermal principles. To these may now be added the "vibration wattmeter," announced in a paper by Biermanns in *Archiv fur Elektrotechnik* for August, 1920. This is similar to a permanent-magnet moving-coil vibration galvanometer, but has two windings in the coil, one used as a current coil and the other, with a non-inductive external resistor, as a voltage coil. Two readings are taken, for the second, the relative direction of current in the two windings is reversed. The power is proportional to the difference of the squares of the deflections. It is said that as low as 10^{-13} watt can be measured.

Considering the question of new developments in apparatus, the makers of watthour meters and demand meters advise, in general, that the effort, during the past year, has been mainly expended in restoring the pre-war quality of output, rather than any considerable amount of new development.

Apparatus continues to be developed for making measurements either of kilovolt-amperes or of the inductive component to be used in connection with rates including a power factor charge.

One of the makers of indicating instruments reports the development of a new line of small size portable instruments (ammeters, voltmeters and wattmeters). These instruments would be of particular interest to those desiring small but accurate and serviceable instruments which can be carried in the pocket or the tool kit.

The makers of precision and recording instruments report the continued development and application of electrical measuring methods and instruments to problems and functions not fundamentally electrical. While electrical methods have been used for years in making laboratory measurements of quantities not electrical, the significant fact now is the wider application of electrical measuring devices for recording and for the actual quantitative control of industrial processes.

Automatic Gas Analysis. Apparatus is now available for the automatic recording of gas analysis. The operation of the apparatus depends on the thermal conductivity of the gases being analyzed. The apparatus is arranged so that variations in the thermal conductivity of the gas being analyzed will cause corresponding variations in the temperature of a resistor having a high temperature coefficient of resistance. The variations in this resistance are recorded by an automatic Wheatstone bridge recorder. Such apparatus finds a valuable application in plants manufacturing hydrogen, oxygen and other gases for commercial purposes.

Electrical Temperature Controller. Equipment has been developed for controlling the temperature of any piece of operating equipment, and particular effort has been made to obviate the trouble due to "hunting" occasioned by the lag between the change in the quantity which is causing the heating and the corresponding change in the temperature of the body under control. The device in question is designed to control the input of the quantity causing the heating in accordance, not only with the actual temperature of the body, but also in accordance with the rate of change of the temperature of the body itself. For instance, if 100 deg. cent. is the limit of temperature desired, it is possible to measure the rate at which the temperature is approaching the 100-deg. point so that the load may be cut off at the proper instant to allow the temperature to drift up to a final limit of 100 deg. cent. without exceeding this value.

The definition of power factor in polyphase circuits which was active last year and mentioned in last year's report as being in preparation by a Special Joint Committee, can be considered as now in the hands of the Standards Committee. A session at last summer's convention of the Institute was devoted to the discussion of this subject and as a result of this open discussion, the Special Joint Committee prepared certain definitions which were reported to the Standards Committee.

The question of standardization of the nomenclature of commonly used electrical instruments and measuring devices was discussed at a meeting of this committee during the year and preliminary steps have been taken, which it is hoped will ultimately lead to the standardization of many names and terms. The work which has been done to date has been confined to the members

of the committee only, in preparing as complete a list as possible of the names and terms to be discussed and standardized. No further report can be made at this time but a brief mention of this activity, however, seems desirable with a recommendation that the succeeding committee continue the work during the coming year.

F. V. MAGALHAES, *Chairman.*

EDUCATIONAL COMMITTEE

To the Board of Directors:

The Educational Committee has been greatly handicapped by the wide geographical distribution of its members, the work being delayed by tedious long-distance correspondence.

The Committee held a meeting in Chicago on November 12, 1920, Mr. Schuchardt presiding, and while only three members were present a plan for the year's work was outlined which later received the approval of all the members. The Committee wished to determine in what respects the technical graduates failed to meet the expectations of their employers and to obtain definite suggestions as to how the product of our Engineering Colleges could be improved. For this purpose a circular letter was prepared and sent to over a hundred prominent electrical engineers, requesting their opinions and criticism. A summary of the replies and a discussion of the suggestions received will be prepared for publication in the JOURNAL.

The Committee believes that a better correlation than obtains at present in curricula, in methods of giving instruction, and in other factors that pertain to college training of engineers may be secured among the several branches of the engineering profession. To gain this end the Committee recommends that arrangements be made for holding a symposium on Engineering Education in 1922 in which representatives from all the National Engineering Societies should take part.

In a resume of the progress made during the year in the field represented by the Educational Committee much or little may be said. A statistical report on new buildings, improved equipment, enrollment and graduation data, and the numerous changes in courses and curricula, would no doubt be extensive, as much progress has been made in these respects; but this information, even if available, would probably be of little interest. The large increase in enrollment has made it necessary for most engineering schools to bend every effort towards meeting the increased demands for equipment and larger teaching staffs to the exclusion of all other interests.

The excellent record made by engineering graduates in the World War is by many taken as prima facie evidence that the training given these men must have been highly satisfactory and that a return to pre-war conditions would leave little more to be desired. In any event, the methods of giving instruction and the training given to engineering students now do not differ greatly from what obtained before the war.

The most noteworthy movement in technical education during the past year, is the extension of plans to greatly increase investigational work and industrial research in engineering colleges. The quickening power of research, the discovery and the development of new principles and new applications, is of more vital importance to educational institutions than to industrial organizations. Effective cooperation on a comprehensive scale, between the research divisions of manufacturing companies and the faculties of engineering colleges, is a consummation devoutly to be desired.

As forerunners of greater things to come the Technology Plan of the Massachusetts Institute of Technology and the Research Department, recently established at the University of Michigan, are of general interest. A better understanding of the problems involved and the solutions effected seems highly desirable. To this end the Committee has requested Dr. C. L. Norton, Director of Industrial Cooperation and Research to prepare a paper on the development of the "Technology Plan" for publication in the JOURNAL. Plans are under consideration for similar cooperative research departments or extension of engineering experiment stations in a number of Universities and technical schools.

C. EDWARD MAGNUSSON, *Chairman.*

INDUSTRIAL AND DOMESTIC POWER COMMITTEE

To the Board of Directors:

The Industrial and Domestic Power Committee during the present term has actively continued its plan of specific study and report on the application of electric power to industry. In the work it has had the help of eleven subcommittes, each headed by a member of the Industrial and Domestic Power Committee as follows:

No. 1—Subcommittee on Motors with Particular Reference to Speed Torque Characteristics. A. C. Lanier, Chairman.

No. 2—Subcommittee on Domestic Power Application. H. Weichsel, Chairman.

No. 3—Subcommittee on Applications in Printing Industry. W. C. Kalb, Chairman.

No. 4—Subcommittee on Cranes and Hoists. R. H. McLain, Chairman.

No. 5—Subcommittee on Applications to Machine Tools. H. D. James, Chairman.

No. 6—Subcommittee on Applications to Passenger and Freight Elevators. H. P. Reed, Chairman.

No. 7—Subcommittee on Applications in the Textile Industry. H. W. Cope, Chairman.

No. 8—Subcommittee on Applications in the Cement Industry. Fraser Jeffery, Chairman.

No. 9—Subcommittee on Applications to Pumps, Fans and Blowers. P. H. Adams, Chairman.

No. 10—Subcommittee on Applications of Electrical Energy in Industrial Heating. M. J. McHenry, Chairman.

No. 11—Subcommittee on Rubber Industry. W. E. Date, Chairman.

A complete roster of the several subcommittees will be found in the Year Book. These subcommittees have worked. Give them and their chairmen the full credit for our work of this term.

The Committee has conducted one Institute meeting at Akron and Cleveland on January 14th, 1921, and under the auspices of Subcommittee No. 11, W. E. Date, Chairman. It was a good practical meeting, with plenty of interest.

We have had one thorough committee meeting, *viz:* on January 14, 1921, at Akron, Ohio, with an attendance of 21.

I recommend that our committee plan and activities be continued another term. I feel that while our apparent results are not large, that nevertheless a constantly widening group in the Institute is becoming familiar with what we are doing and is taking interest in it. With patience and encouragement the plan will continue to grow in interest and value.

As a portion of this report is submitted a report of progress in the Industry prepared by Mr. W. C. Yates of our Committee and also a full report from the Chairman of each Subcommittee. I recommend these several reports for your careful consideration.

As a committee we have tried hard to make our work of value. It is of value. The work that individuals and groups of two or three have put in with resulting monographs are notable contributions to the Institute files and as Chairman of this Committee, I can do no less than direct attention to them.

I also commend to you the help and efficiency constantly accorded us in our work by the Secretary of the Institute, and those associated with him.

A. G. PIERCE, *Chairman.*

Industrial and Domestic Power Applications—Progress of the Art During the Year 1920

By W. C. YATES

Despite the fact that industrial activity slumped decisively during the latter part of the year 1920, the first three quarters of the year compensated for this to such a degree that the sum total of the industrial and domestic electrical equipment installed during the year was unquestionably greater than in previous years.

The use of electrically-driven domestic machinery, such as washing machines, vacuum cleaners, etc., showed an unprecedented growth until the business depression set in. An astonishing amount of such machinery was installed for the benefit of thousands of housewives, and this was especially true of washing machines. All this required no special developments in the way of motors, switching devices, etc., because suitable types of such electrical equipment were already available.

Turning to the industrial field in general, it may be said that considerable advance was registered in the incorporation of safety features in both motor and and control appliances, especially to the latter. The use of 50-deg. motors as compared to the old 40-deg. ratings increased and there was evidence of much more accurate study of the power required to drive machinery and a closer selection of the motors to do the work. This necessitated in turn the evolution of more overload protective devices, in which connection considerable improvement was made during the year.

In certain fields of industry no particular advance in the art occurred during the year 1920 to be particularly worthy of mentioning. In other fields definite steps in advance were made of which the following are worthy of note:

Mining. The activity in mining was not quite up to that of former years, but a number of interesting large equipments and an unusually large number of small hoist motors from 100 to 250 h. p. were installed or under construction at the close of the year. The McKinney Steel Company's hoist at Bessemer, Michigan, was put into commission. This is the largest d-c. iron ore hoist in the United States. It is driven by a 1650-h. p. 80-rev. per min. direct-connected motor.

Steel Mill. A record was made in the number of electric main roll drives put into commission. Improvement was shown in the accuracy of the speed control provided.

Considerable improvement was made in the control devices, especially of the magnetic type for steel mill auxiliary machinery, this improvement having to do with the better wearing qualities of the contactors and consequent longer life of the control equipment.

Machine Tools. In this field the development of motors and controllers for high-speed woodworking machinery stands out most prominently. This application required specially designed motors operated at frequencies as high as 300 cycles.

Textile Industry. An interesting development involved the application of individual drive to a series of tentering machines for starching and drying cloth where three independent rolls, each driven by an individual motor, were tied together by an automatic control equipment that insured the same speed of the fabric through the three machines. This same tie in of two or three machines to run at the same speed was accomplished in the printing of cloth and did away with expensive line shaft equipment very apt to get out of order.

Paper Mill. A new form of sectionalized motor drive for paper machines was developed, each section being driven by an independent motor, the speed of which

with relation to the speed of the other sections may be regulated to suit the requirements, and when once adjusted will retain this relationship as positively as though geared together.

A typical installation of this new drive was to a paper machine consisting of nine sections and employed in the manufacture of newsprint. This machine is designed for high-speed operation, producing paper 164 inches wide at the rate of 1000 ft. per minute. Eight sections of the paper machine are each equipped with a 100-h. p. 136-rev. per min. shunt-wound motor direct coupled, while the reel is driven by a direct-coupled motor of 30 h. p. These nine motors are supplied with power on a Ward Leonard system from a 600 kw. 250-volt turbine generator, and the speed of the machine as a whole is controlled by the voltage of this generator, the fields of the motor being excited from the same excitation source as the generator. The motors have the same speed regulation from no-load to full load.

The novel feature of the installation consists of 20-h. p. synchronous motors, one of which is mounted on the base of each of the d-c. motors, and is connected to the main motor by means of a gear and a pair of cones belted together with an eight-inch double-ply belt. The function of these synchronous motors is to rigidly tie together the various sections of the paper machine and maintain a positive unvarying speed relation between them.

Oil Well. The demand for oil well motors continued to increase in both old and new oil fields. The power companies were unable to supply ample power for this purpose.

In Los Angeles County the deepest electrically drilled oil well in the world was completed in June and its depth was 4650 ft., this being the "Anita A" well of the Shell Company of California.

Another development of the year in Southern California oil fields was the application of motor drive to deep drilling by the rotary method. This has progressed to a stage which gives every indication of its complete success.

Handling of Coal, Ore, etc. Improvements may be noted in the machines developed to handle coal, ore, and other bulk materials, although this involved no new developments in the electrical apparatus. A particularly interesting installation is the coal loading pier of the Baltimore & Ohio Railroad Company at Curtis Bay, Md. This was improved last year by the addition of four trimming machines. It is now possible to load a 10,000-ton boat in eight hours.

Elevators. Mention may be made here of the application of the two-speed a-c. motor to elevator service, the motor having two windings and the lower speed being employed for making landings.

Pumps and Fans. Particularly worthy of note is the increased use of synchronous motors in the operation of pumps and fans.

Logging. A unique installation which will undoubtedly have considerable influence on the future of the lumbering industry consists of a combined outfit of electrically-operated yarder and loader hoists which was placed in service in August, 1920, by the Snoqualmie Falls Lumber Company of Snoqualmie, Washington. The yarder is operated by a 200-h. p. 600-rev. per min., three-phase, 60-cycle, 550-volt motor of special construction designed particularly for the very high torque which is essential in yarder service.

The loader, which lifts the logs brought in by the yarder, is a duplex outfit with two hoists, each gear-driven by a 75-h. p. slip-ring motor. These hoists are not provided with mechanical brakes, but each has two electrical brakes, one being the standard type and the other a solenoid load brake which has inherent graduated braking characteristics. The reason for this double brake equipment is to secure low and fully controlled lowering speeds when placing the heavy logs on the cars.

Electric Shovels. Considerable improvement was made in the application of electric drive to shovels. The chief improvement involved the use of the Ward Leonard system in the individual drive of the several motions of the equipment.

Advance was made in the design and application of equipment for arc welding, electric furnace work and in other fields. A report of this kind cannot possibly cover the ground in any detail as it is only intended to point out the steady advancement of the art in the broad field of industrial and domestic power.

[This report to the Board of Directors was supplemented by a statement from each of the sub-committee chairmen, giving an outline of the plans and the work accomplished to date of each of the sub-committees.]

TELEGRAPHY AND TELEPHONY COMMITTEE

To the Board of Directors:

The following report contains a review of the engineering of Telegraphy, Telephony and Radio Communication during the Institute year 1920-1921.

Wire Communication along Railroads

Technical developments of the past year have placed the telegraph and telephone departments of railroads in the United States and Canada in a more serviceable condition than they have heretofore been. The work of the technical committees of the Telegraph and Telephone Section of the American Railway Association has been added to by the institution of committees handling the subjects of telephone transmission, radio and wired radio communication, and technical education for employees. A considerable number of new undertakings are now about ready for service trial in the field. Improvements are embodied in recommendations submitted by committees working

on the problems of protection against lightning disturbances, inductive interference, electrolysis, wire transpositions and stronger pole line construction.

The Railroad Administration's trunk circuits radiating from Washington, D. C., were promptly discontinued at the termination of Federal control of the railroads, and the wires returned to the control and use of the individual railroads. The general interchange of wire service between the various roads, through connecting railroads not concerned in the purpose of the communication, was at the same time discontinued.

The employment of recent types of telephone repeaters has been arranged for by a number of the large railroads for the purpose of improving long distance telephone service. On the New York, New Haven and Hartford Railroad the installation was completed of an aerial cable between New York and New Haven. Circuits in this cable have telephone repeaters, and on some pairs loading coils are provided.

The subject of stronger pole lines has been given serious attention on many railroads. On some lines the factor-of-safety plan of construction has been extended.

During the year the increase in telephone lines has not been great, due mainly to retrenchment following temporary business depression.

Some progress has been made in replacing older types of calling selectors, and changing the method of operation of others in order to obtain low-resistance simplexes for telegraph service. Also, some tests have been made with wire-guided carrier-current signaling in conjunction with engineers of the United States Signal Corps under the direction of Major General Squier, Chief Signal Officer.

The practise of welding joints in exposed lines has been extended.

Printing Telegraph Systems

The application of automatic printing telegraph systems to commercial requirements is being extended, both in the United States and Canada. A noticeable tendency is the gradual standardization of apparatus and of methods. Development generally is along the line of reducing equipment maintenance costs by simplifying the various printer units and making them more substantial mechanically.

For trunk circuits carrying heavy traffic the multiplex system is being widely applied. A multiplex system provides two or more two-way channels per wire. The ease with which the multiplex system may be made to meet traffic growth—simply by the addition of operating tables and associated equipment—is one reason for its success. Another reason is that it allows taking full advantage of the signaling capacity of a wire. With the multiplex it is possible to handle eight hundred or more messages per hour over a single conductor; correct incidental errors instantly, and have every message so handled ready for delivery to the addressee as soon as it has passed over the wire. An objection to older automatic systems was the time required in preparing the message for delivery after its receipt. There was also delay in correcting incidental errors.

A new field being entered by printing telegraphs is that including private branch offices, and way-office circuits. Developments in this direction center on the problem of producing a tape-printing machine so dependable as to require only occasional attention from mechanics, and so simple in operation as to be handled satisfactorily by an ordinary typist. A promising use for this system is its employment by commercial concerns and industrial establishments for intercommunion purposes and for communication between business offices and telegraph offices.

"Start-Stop" Printing Telegraph Systems

In all modern printing telegraph systems the principle of synchronism is employed. Systems employing continuous synchronism require that the apparatus at the transmitting and receiving stations be in phase at all times, and usually consist of distributors having constantly rotating arms operating in unison. Continuous synchronism is generally used when more than one simultaneous transmission over one wire is desired.

Systems not employing continuous synchronism, but providing instead that a signal be transmitted to start from a position of rest the arms of the transmitting and receiving distributors or their equivalents, are called "Start-stop" systems. The arms of the transmitting and receiving distributors are timed to rotate at practically the same speed for one revolution and then come to rest—one rotation for each letter, figure or other character.

The start-stop systems of recent American development use the five-unit signaling code. For circuits where the traffic requirements are such as to call for a speed of sixty words per minute, start-stop systems are satisfactory and their use is being extended. Such circuits are operated duplex over distances of 300 miles without intermediate repeaters. The employment of repeaters permits operation over greater distances.

Start-stop systems may be grouped into two classes. In the first, the distributor, transmitter and printer are separate units. With systems of this class a speed of approximately sixty-five words per minute is possible. In the second class, the distributor, transmitter and printer are self-contained in a single unit, the transmitter being controlled by a typewriter form of keyboard. Systems of the second class are also known as simplex printers and are operated at a speed of about fifty words per minute.

Submarine Telegraph Signaling

From the year 1858 until 1871 submarine cables were operated in one direction at a time only. Since the

latter year, cables have been operated duplex. From 1871 until 1908, important improvements were made in existing apparatus. In the latter year "magnifiers" were introduced which permit operation of long cables with considerably reduced line current strength, with consequent increase of signaling speed—50 per cent or more above previous speeds.

In recent years a tendency in cable signaling has been to introduce terminal apparatus aiming at reduction in operating costs. Tape perforators of the mallet type have been replaced by perforators having keyboards similar to those of a typewriter, permitting largely increased output per operator in a given time. Automatic transmitters are used which insure continuous transmission of uniform signals. Automatic relays have been installed to connect together sections of cables to permit direct working without the necessity of manual relaying of messages. In some cases instead of direct automatic relaying a re-perforator is introduced which is actuated by signals from one section of cable perforating a tape which feeds into a transmitter sending into an adjoining section of cable.

Considerable progress has been made in applying printing telegraph systems to submarine cables. Experimental installations have been in actual service operation during the past year or two. The application of printing telegraph systems to ocean cables reduces operating costs and, perhaps to some extent, increases operating speeds. Further improvements now being made in ocean cable printing apparatus will result in much simplified equipment with promise of an increased output in unit time.

Protection of Lines Against Lightning Disturbances

No radical changes have recently been made in the character of protection installed on communication lines for protection against lightning disturbances, but the growing need for continuous operation of lines has renewed interest in developing efficient self-restoring lightning arresters. Some of the more dependable existing types of arresters have been improved with the object of bettering the protection and lessening circuit interruption after static charges have been dissipated. Present types of arresters embody the principles of the airgap, vacuum gap, and choke coil.

Reduction of Inductive Interference

Promising progress has been made during the year toward the solution of the problem of inductive interference control and reduction. The growing difficulties in keeping communication and power circuits in well separated locations—attendant upon the rapidly increasing demands for these services—has brought a real appreciation of the need for thorough and systematic attention to the coordination of the engineering of these facilities.

As a consequence, increasing effort is being directed toward learning sound methods of coordination, and toward the application of these methods in the initial planning of construction. Prominent among these efforts toward more systematic treatment of the problem are facilities inaugurated by the National Electric Light Association for centralized study by a committee and engineering staff specializing in this subject.

It is an indication of sound progress that the problem is now recognized as of mutual concern by the various electric utilities. The trend is clearly toward cooperative study and treatment as in the best interests of these utilities.

Noteworthy in this direction is a step taken by the American Telephone and Telegraph Company and the National Electric Light Association in developing broadly laid plans for cooperative procedure in working out and applying methods for the control and reduction of inductive interference with telephone service.

So far as the committee has learned there has been no outstanding development during the year in the form of specific devices or methods applicable to either the communication or power facilities for inductive interference reduction. It is, however, of interest to note that the engineers of the American Telephone and Telegraph Company have developed and given some preliminary field use to a new type of noise meter," designed to measure the degree of disturbance indicated in a telephone receiver without bringing in the personal factor of the observer in judging equivalent noise as is the case with the older "noise" standard employed by the telephone companies.

Automatic Telephony

During the year there was in general a continuation of refinement in the design of automatic telephone apparatus. So far as radically new deve opments are concerned no epoch-marking inventions have been disclosed.

Further progress has been made in standardization of apparatus and in details of maintenance and operation. The undertaking to standardize nomenclature resulted in the publication of about 100 definitions of current terms.

There have been placed in service three devices the introduction of which may have an important relation to the further development of the art:

1. The call indicator, used in calling from an automatic office to a manual office during the period of mixed working, which displays the call number before the operator and permits automatic subscribers to dial all numbers.

2. A calling device number plate with office names in addition to numbers, to permit retention of office names in small multi-office exchanges converted to automatic.

3. A calling device number plate with the alphabet in addition to the numerals to enable the first few

letters of the office name to be used as numerals in a large multi-office exchange.

Carrier-Current Telephony and Telegraphy

At the Midwinter Convention of the Institute there was presented a paper on "Carrier-Current Telephony and Telegraphy," by two members of the committee, Messrs. Colpitts and Blackwell, which gives a history of this art; states the fundamental principles which underlie it; discusses the action of open-wire lines and short lengths of cable to the frequencies used in carrier operation, and describes the carrier systems which have been developed and put into commercial use in the Bell Telephone system. The historical part of this paper is interesting, showing the principles underlying carrier-current operation as having been worked out at an early date, but that economical use of such systems was not possible until the introduction of the three-electrode vacuum tube as a modulator, demodulator and amplifier; until the art of transmission over wires, including repeater operation, had been developed to its present state, and until the development of electric filters had been carried to the point permitting effective utilization of comparatively low carrier frequencies.

The commercial telephone installations described give four added telephone circuits over each pair of line wires in addition to the usual telephone and telegraph facilities provided by the wires. Commercial telegraph systems provide as many as ten added duplex telegraph circuits, also in addition to the usual facilities.

As pointed out in the paper, the apparatus involved in such systems is necessarily complex and, therefore, expensive, so that systems of this type are in general economical only for comparatively long circuits.

Radio Telegraphy

Radio communication during the past year has undergone a reorganization of ownership of the important patent rights which should relieve a very complicated situation and result in placing in use equipment superior to that heretofore employed. The radio companies are now in a position to proceed without imminent fear of infringement of essential patent rights.

The superior serviceability of continuous waves, with beats reception, has been recognized and the principle is being extended in practise.

The ease with which short waves can now be controlled from electron tubes has had much to do with the rapid change in the practise of the art. Spark transmitter systems, for all but ship emergency uses, are no longer planned for commercial operations.

With the more general use of continuous wave systems and the resulting greater possibilities of selectivity there is a strong legislative sentiment in favor of more liberal regulations. The use, with continuous waves, of a large number of working wave-bands, with a reserved emergency and calling band, will do much to eliminate the interference and troublesome delay which now exists at each of the several important ocean harbors. The sentiment that favors greater freedom in wave-band selection also favors the enforcement of more rigid requirements of purity of radiation and the securing of minimum damping at transmitting stations.

Transoceanic service has been further improved with a resulting increase in the volume of traffic handled and in the quality of service rendered. The gradual elimination of minor defects that commercial operation has brought to light has resulted in pronounced improvement in continuous operation over long distances.

The accomplishments in static elimination, permitting the better utilization of means of amplification of signals, have done much to overcome operating variations due to atmospheric disturbances and other causes.

A broadening of the field is noticeable in adapting radio systems and methods to new uses, and several such applications are looked for in the immediate future. The remote control of switches by means of radio is now being considered.

The superheterodyne method of reception, due to E. H. Armstrong, stands out as an important contribution of the past year.

Radio Telephony

The progress of radio telephony during the past year has been in the direction of the application of the three electrode tube, developed during the past seven years, to a point where it serves as an amplifier delivering comparatively large power, or as a reliable detector or telephone repeater, to the problem of supplying radio service of a commercial character in connection with existing wire.lines.

This progress in all its phases is illustrated in a radio telephone toll circuit now in commercial operation in the territory of the Pacific Telephone and Telegraph Company, furnishing telephone service between the Island of Santa Catalina and the wire network of the mainland centering in California.

The Avalon-Los Angeles radio toll circuit is believed to be the first radio telephone installation in the world to be opened for public service. The service was inaugurated on July 16, 1920. The radio circuit is operated according to wire line methods. The operating circuit is from Los Angeles, Cal., to Avalon on Catalina Island. The radio section is between two coastal stations thirty-two miles apart. The circuit is provided with through line ringing of a type which is free from interference, and a superposed telegraph circuit capable of forming a link in a duplex wire telegraph circuit. The transmission and quality over the circuit are of such high standards that it is regularly connected, when required, into the long distance telephone circuits. On several occasions conversations have been carried on between the S. S. *Gloucester* in

the Atlantic Ocean, and the Avalon office in the Pacific Ocean, the transcontinental telephone wire line being used as the connecting link overland.

The extensive application of types of electric wave filters in transmitting and receiving circuits has made it possible to obtain a good quality of speech and at the same time to secure greater selectivity than was possible with the prior art. The use of loops for receiving and of shorter wave lengths for short distances had to some extent reduced interference.

Standardization of Terminology

A sub-committee of the Standards Committee of the Institute has been engaged in the work of formulating standard definitions of terms most commonly used in telegraphy, telephony and radio signaling. The importance of such work, especially in the case of an art developing as rapidly as is the art of electric communication, is obvious. Not only is it of advantage to eliminate ambiguous and superfluous terms, and terms wrongly used or etymologically incorrect, although these may have come into extensive use, but it is especially important to select the most logical and appropriate terminology called for by the development of the allied arts so as to get a proper start and thus, in a large degree, avoid the necessity for later revision, and perhaps at a time when incorrect terms have been widely adopted in operating practise.

The terms so far chosen and defined have been simply and unequivocally, though broadly, defined in the light of a comprehensive survey of the field to which they are appropriate, thus eliminating the necessity of a multiplicity of terms covering slightly different applications.

Consideration also has been given to bringing about agreement so far as practicable between English speaking countries. In quite a number of instances the same term is given different meanings, or different terms are employed to convey the same meaning. The sub-committee on Telegraphy, Telephony and Radio is, therefore, cooperating with a corresponding committee of the British Engineering Standards Association, with the above mentioned object in view.

The Bell and independent telephone interests have found it mutually advantageous to unify not only operating methods, but also operating phraseology, for the purpose of facilitating the handling of interconnecting traffic involving cooperation between two groups of operators. This supplies an excellent illustration of the value of standardization as applied to terminology which can promptly be translated into dollars and cents.

Education in Communication Engineering

Considerably greater attention is now given in American universities and technological schools to instruction and research work in communication engineering. Sheffield Scientific School, Yale University, has an organized course in this field as has the Massachusetts Institute of Technology, and Columbia University, New York, has a course in submarine cable engineering. The College of the City of New York has a thoroughly equipped and organized communication laboratory, and at a number of the United States Army Departmental headquarters, or in their vicinities, thoroughly organized and equipped schools are maintained which cover these subjects.

In addition, the programs announced for the rapid introduction of automatic or machine switching in telephony, and the continued development of machine telegraphy will necessitate the instruction of large numbers of present employees of the operating companies, as well as recruits, who will be required to install, supervise and maintain the equipment. In this connection it is recognized that it is especially desirable speedily to perfect the terminology and thus to make available a common language for teaching purposes as well as for field use.

There is a noticeable drawing together of the engineers of the arts of telegraphy, telephony and radio signaling. The communication engineer of the immediate future will have to be well versed in the engineering of the three divisions of the general subject.

There are approximately six hundred communication engineers identified with the Institute, and the number is now increasing at the rate of about forty applications per month.

This report has been made up to include contributions forwarded by the following members of the Telegraphy and Telephony Committee: O. B. Blackwell, R. E. Chetwood, E. H. Colpitts, Charles E. Davies, H.W. Drake, S. M. Kintner, Stanley Rhoads, A. E. Silver, Arthur Bessey Smith and F. A. Wolff.

Donald McNicol, *Chairman.*

POWER STATIONS COMMITTEE

To the Board of Directors:

The work of the Power Stations Committee during the past year has included the routine work in connection with the analysis of papers bearing on power station subjects, which were referred to the committee for attention. In addition, the committee arranged for the presentation at the March meeting of the Institute of a paper entitled *Developments in Conversion Apparatus for Edison Systems*, by T. F. Barton and T. T. Hambleton. The committee also considered the suggestions of last year's committee, and gave considerable thought to the preparation of a symposium on auxiliaries in steam and hydroelectric plants. While a certain amount of work has already been done on this subject, because of the limited amount of time available, further action has been postponed,—the recommendation of this committee being that the incoming committee continue the work which has been started with a view to presenting a symposium on this subject during the early part of the coming year.

In accordance with the request of the Board of Directors, your Committee presents in this report a brief outline of the progress of the art and the most important developments in power station work during the past year. There is also included an appendix, which is an abstract of the bibliography of the important articles treating of power station design and operation appearing recently in American and foreign technical journals.

During the past year, there have been several notable power station developments which have recently been placed in service, or are now in course of construction. These plants are of large size and incorporate many new and interesting features of design, particularly in the details of plant layout and the combination and application of auxiliary equipment.

Among the recent installations may be mentioned the Colfax power station in Pittsburgh, the Hell Gate Station in New York City, the Delaware station in Philadelphia, and the Calumet station in Chicago.

The Colfax power station represents the latest development in the so-called "mouth-of-mine" plant. This type of plant is of especial interest at this time, in view of the trend toward interconnection. It is essentially a design of the type most suited to bulk generation and distribution of power.

The Hell Gate, Delaware and Calumet stations are designed particularly for metropolitan service where a relatively large number of feeders at generator voltage are provided for the distribution of power. In the design of these plants, however, particularly the Hell Gate and Calumet stations, certain marked changes have been made in the general arrangement of busses and high-tension switching equipment.

In the use of auxiliaries, there is to be noted a decided trend toward electric drive. Two of the outstanding features in this development are the application of 2300-volt motors in sizes of 100 h. p. and over, and the use of differential relay protection of the various motor circuits. Considerable attention has been given also to the layout and protection of all auxiliary circuits as well as improvements in the motors and control equipment to insure continuity of service. These features are of vital importance in the modern power station. The increase in the use of electric power for auxiliary drive has been relatively large and involves a number of problems which were not considered of prime importance when the size of the electric installation for auxiliaries was comparatively small.

It is further recognized that conditions in power station service are different from the usual industrial plant, and it is to be noted that the development of present control equipment, which heretofore has been based largely on the experience gained in industrial service, is now being given the attention required for power plant service, where the necessity for continuous operation over long periods requires greater liberality in details of design than has heretofore been considered necessary.

Turbine Generator Units

The past year marks a number of improvements in details of design and construction of turbines. A more careful selection of material, closer inspection and improved testing facilities, particularly in connection with static and dynamic balancing of rotating parts, have had an important bearing on increased reliability and economy of operation.

There was also evidenced a definite change in attitude toward the use of larger generating units. The records of the past year show no increase in the size of single-cylinder steam turbine units, the largest unit of this type being of 45,000 kw. capacity. In two of the largest stations under construction in 1920 and 1921, the generating units have been 30,000 and 35,000 kw., respectively. There are, however, now in operation, a number of 40,000- and 60,000-kw. cross-compound units, consisting of two or three 20,000-kw. generators, which show satisfactory performance in point of continuity of operation and overall efficiencies.

In 1920, the two manufacturing companies engaged in building large turbo-generators, took contracts for 23 units of 20,000 kv-a. capacity, and larger. These 23 units aggregated 800,000 kv-a. and 690,000 kw., the average size unit being 35,000 kv-a. and 30,000 kw. It is interesting to note, in this connection, that of the 23 large units purchased in 1920 only five were for 25-cycle operation, and these units were purchased for installation in New York City.

In large hydraulic installations, the 90,000-kw. development at Niagara Falls, placed in operation in 1920, and the 350,000-kw. plant of the Hydro-Electric Power Commission of Ontario are noteworthy for their large capacity and new features of layout and installation. The No. 3 Station extension of the Niagara Falls Power Company is notable in delivering better than 90 per cent of the available energy of the water to the generator terminals. It is also of interest to note that the 45,000 kv-a. generators and turbines now under construction for the Hydro-Electric Power Commission, will, when completed, be the largest hydroelectric units thus far placed in operation.

Closed Air Ventilating Systems

A comparatively recent development in turbo-generator cooling is the closed air circulating system, in which a definite volume of air is circulated continuously. There is a closed air path consisting of the generator and short connecting ducts to some device for removing the heat from the air. This cooling device may be the familiar spray washer, analogous to a jet condenser; or the hot air may be passed over tubes through which cold water is circulated, analogous to the surface condenser. Some installations of the closed air system with water tube coolers have been completed in England, and several trial installations have been projected in this country. There are a few installations of the closed air system in operation in this country, using the spray cooler.

The principal advantages claimed for the closed air system are effective elimination of dirt from the generator and reduced fire risk. The water-tube cooler has the additional advantage of eliminating all danger of water or ice entering the generator. There have been a few winding failures from this cause in this country, and apparently a considerable number of such failures in England, which, according to information received, accounts for the more active development of the water-tube cooler abroad. Whether these advantages of the closed air system will compensate for the obvious disadvantages of increased complication and congestion in the station layout and the appreciable increase in cost (in the case of the water-tube cooler), only further study and experience can determine.

Large Power Transformers for Station Use

Single-phase transformers of a capacity of 23,600 kv-a., 60 cycles—larger than any heretofore constructed—have been supplied during the past year for stepping up from generator voltage to a present transmission voltage of 66,000 volts and an ultimate of 132,000. A bank of three single-phase transformers takes care of the entire output of a 60,000-kw., 11,500-volt, turbo-generator unit. The transformers are connected in delta on the low voltage side, and star on the high voltage side. Each transformer weighs 126,000 lb., requires a floor space of 11 ft., 3 in. by 10 ft. 3 in., and measures 23 feet from the rail to the tip of the high voltage bushing.

The largest single-phase, 25-cycle, transformers ever built are being constructed for the new Queenston-Chippewa project of the Hydro-Electric Power Commission of Ontario. These transformers are of the shell type; are rated at 15,000 kv-a., and are arranged to step up in banks of three from a 45,000 kv-a. water-wheel generator to a present transmission voltage of 110,000, and ultimate voltage of 132,000. Transformers are connected in delta on the low-tension side, and star on the high-tension side. Each transformer weighs 186,000 lb., requires a floor space of 11 ft. 6 in. by 10 ft. 6 in., and measures 28 ft. 2 in. from the rail to the tip of the high voltage bushing.

For a number of years the maximum voltage for commercial transmission remained stationary at about 150,000 volts, but during 1920 this was raised to 165,000 volts, and transformers are under construction for operation on a 220,000-volt, 60-cycle system now being built. Core type transformers of 16,667 kv-a. and 8,333 kv-a. are being built, arranged for 11,000 volts on the low-voltage side, and 127,000 volts on the high-voltage side, so that three transformers may be connected in star for 220,000 volts.

These transformers are designed for grounded Y service and are equipped with one high-voltage bushing, the other end of the winding being permanently grounded to the tank to form the grounded neutral.

The windings of the 16,667 kv-a. transformers are so arranged that the 220,000-volt line lead is at the center of the column of coils, hence the potential to ground decreases towards the ends of the column, so that the coils nearest the yokes of the core are at or near ground potential. These transformers weigh 158,000 lb., require a floor space of 14 ft. 5 in. by 11 ft. 8 in., and measure 22 ft. 9 in. from the rail to the tip of the high-voltage bushing.

Among the large air-blast transformers produced were five 4550 kv-a., 10,900 Y/210-volt units for use with synchronous converters for the d-c. system of the New York Edison Company. These transformers are of high inherent reactance and are used in conjunction with the synchronous converters without the use of synchronous boosters to obtain the necessary range in continuous voltage, this voltage range being secured through the compounding characteristics of the synchronous converter in conjunction with the transformer reactance.

The operating reports during the year demonstrate the value and the greatly extended use of the oil conservator on large and high-voltage transformers. The utility of this feature is becoming more definitely established by the protection afforded from condensation of water in the transformer oil, the elimination of possible gas explosions due to decomposition of the oil and the gases so produced mixing with air at the top of the tank, and to the practical elimination of sludging of the oil due to oxidation when in contact with air at fairly high temperatures.

Switching Equipment

In general, it may be said that there is a decided tendency toward simplification in station layouts and details of design. Complicated switching connections to take care of possible contingencies have been replaced by simpler layouts, resulting in reduced costs and marked reduction in operating troubles. Particular care is evidenced in switch-house layouts in the provision for safeguarding against serious trouble in case of switch explosions or oil fires. It has been recognized as advisable to provide as far as possible for greater space and greater accessibility to all parts of the electrical equipment using oil.

The semi-outdoor type of construction which has been adopted by the Niagara Falls Power Company at their Echota substation, is the most recent example of a departure from the standard type of switch-house construction designed for the purpose of preventing as far as possible the danger from oil explosions. The switches in this case are erected in structures in such a way that the operating mechanisms are covered, but there is no enclosure in front of the oil switch pots so that the force of any explosion which might occur is not in any way confined.

Bus Construction

Considerable attention has been given to the recent designs of switch house and equipment. Increased

station capacities with the possibility of increased short-circuit stresses, call for a more substantial type of construction than has heretofore been considered necessary. One installation on record incorporates a type of bus support designed to satisfactorily take care of short-circuit stresses of 10,000 lb. applied at right angles to the top of the support. Greater attention is also being given to the layout of conductors, the avoiding of loops in the circuit wherever possible, and the provision for increased space between conductors so as to minimize the effects of magnetic stresses. In the new station of the Hydro-Electric Power Commission of Canada, at Queenston, the busses are arranged horizontally instead of the usual vertical arrangement, and are mounted on five-foot centers on the floor with concrete barriers between phases.

A radical departure in the arrangement of busses and switch-house connections is incorporated in the designs of the new Calumet Station of the Commonwealth Edison Company, Chicago, and the Hell Gate Station of the New York Edison Company. The principle adopted in these stations is to separate the phases of each circuit, putting them into what practically amounts to separate rooms, thereby eliminating the possibility of flash-overs, oil switch explosions, or other troubles resulting in short circuits due to the close proximity of all three phases. This layout has involved the design of new switch-operating gear so that the pots of each phase of an oil switch may be operated simultaneously from a single operating mechanism.

Oil Circuit Breakers

The most important development in oil circuit breakers has been in the extremely heavy-duty type. The latest designs are for units having a rupturing capacity approximately twice that of any previous breakers constructed, or 58,000 arc-amperes at 15,000 volts. This has necessitated designing the circuit breaker structure of sufficient strength to withstand shock and internal pressures in excess of any previously encountered. It has also required a design of the conducting details that will withstand the heavy magnetic stresses resulting from heavy short-circuit currents encountered only in the largest systems.

For substation and auxiliary power service, there is a trend toward the truck type of circuit breaker. The designs that are being constructed are fully protected by interlocking features to guard the safety of the operators.

Paralleling the high-voltage developments in transformer design, there has been a corresponding advance in oil circuit breakers for 220,000-volt service for heavy interrupting duty. These breakers are physically the largest ever constructed, the tanks being 8 ft. 6 in. inside diameter, and 11 ft. high. The height to the top of the terminal bushing is 20 ft. For a three-pole unit, a floor space of 10 ft. by 30 ft. is required.

Reactors

Developments are still under way in the design and application of reactors, particularly as affecting certain mechanical features which have not given highly satisfactory results in operation. These changes have been made, and for present service conditions, the performance of this type of equipment can be considered fairly reliable.

A phase of the subject which is being appreciated more today than heretofore is the necessity for guarding against the introduction of too high a reactance in the tie-line connections between stations or large systems. Too low a reactance on large systems, particularly, will result in excessive energy transfer at time of trouble; and, on the other hand, too high a reactance will result in decreased synchronizing power, with the resulting operating complications at times of system disturbance. The subject of synchronizing power between stations as influenced by characteristics of equipment and tie-lines, prime movers and excitation, is one which warrants the most careful consideration.

Disconnecting Switches

The design of disconnectors is undergoing the same improvement as has occurred in other bus and switching connections. The danger of the loaded disconnectors being opened is being removed by the very general use of pilot lights connected to the corresponding oil switches and by mechanical interlocking of the disconnectors with the oil switches. In the case of the new Calumet Station in Chicago, the disconnectors will actually be operated simultaneously with the oil switch by mechanical interconnection so arranged that the disconnector opens immediately after the opening of the oil switch and the disconnectors close immediately before the closing of the oil switch. In some stations, the interlocking is arranged on the doors in front of the disconnectors, thus safeguarding against the opening of the switch before the corresponding oil switch has been opened. The rather frequent mistake of operating the wrong set of three disconnectors has been taken care of in some cases by a system of links and levers which operate all three disconnectors, or, in some cases, even six disconnectors, by the manipulation of a single lever which then may be locked in the open position if necessary.

Operating Instructions

Several companies have, during the last few years, prepared detailed operating instructions for their operating and maintenance attendants, covering the operation of transmission and station equipment. The value of such instruction lies in replacing the word-of-mouth transmission of operating experience through a constantly changing operating personnel. Carefully-prepared, written instructions make it possible for operating attendants to be transferred to different

watches and to work in different groups without the necessity of the men getting used to each other's peculiarities of operating procedure. It facilitates the rapid breaking in of new men and makes the methods of operation more independent of personnel. The preparation of such instructions entails a large amount of painstaking labor, but in the opinion of those who have done so, is entirely justified by the results obtained.

H. P. LIVERSIDGE, *Chairman.*

APPENDIX A

Important Articles on Power Station Design and Operation that have Appeared in American and Foreign Technical Journals

A — STATION DESIGN, OPERATION AND COSTS

"Efficient Operation of Central Power Stations," by J. D. Morgan. *Power*, October 7, 1919. This article presents data and curves dealing with the operation of every unit and of the station as a whole and the systematic testing of all units to detect the falling off in efficiency and the exact cost of operation in the various departments of the plant.

"Development of Automatic Hydroelectric Generating Stations," by T. A. E. Belt. *Electrical World*, February 28, 1920. The author deals with the automatic operation and remote control especially applicable to small and medium sized developments and the use of synchronous and induction generators for this service.

"Power House Foundation," by E. M. Lurie. *Power Plant Engineering*, February 1, 1920. Information is given on methods for testing soil, column footings, drainage and other construction problems in securing permanency of foundation.

"Automatic Hydroelectric Stations," by T. A. E. Belt. *Electrical World*, April 10, 1920. Details are given covering the operation of the automatic hydroelectric generating station of the Iowa Railway and Light Company at Cedar Rapids, Iowa and the remotely controlled hydroelectric generating station of the Ontario Power Company of Ontario, California. Details of a proposed automatic system are given which will tie into a tranmission system which is fed by two very large steam driven generators.

"Water Station of the Southern Power Company," by W. S. Lee and Richard Pfaehler. *Electrical World*, May 8, 1920. Details and construction are given for a 90,000 h. p. generating station and outdoor switching station (the largest of company's system) designed to provide for operation under extreme conditions of floods of large magnitude.

"Data on Output and Load Factor of Largest Generating System in America." *Electrical World*, May 8, 1920. For all lighting, power and electric railway companies in the United States and Canada operating generating stations with outputs in excess of 100,000 kw-hr., the following data are tabulated for the years, 1917, 1918, and 1919: Peak load, date of peak load, yearly output, yearly load factor.

"Steam-Electric Generation in Far West," by W. F. Durand and C. H. Delany. *Electrical World*, May 15, 1920. Present tendencies in the design of generating stations on the Pacific Coast are outlined from the standpoint of fuel consumed, operation with hydroelectric systems, and the size of generating station required. Automatic control is also discussed.

"Importance of Control and Signalling Circuits in a Power Station," by Probst. *Elektrotechniche Zeitschrift*, January 29, 1920. The author emphasizes the importance of clearness and neatness in mounting all auxiliary conductors and shows on photographs and tracings some examples of the *A E G* back of panel wiring system.

"Stabilizing Large Generating Systems. *Electrical World*, July 3, 1920. Abstract of features brought out by Dr. C. P. Steinmetz and R. F. Schuchardt in papers presented before the American Institute of Electrical Engineers. Operating conditions in the three large power houses of the Commonwealth Edison Company are outlined, giving an analysis of cable failures and the use of reactors. Conclusions drawn by Dr. Steinmetz regarding the use of power limiting reactors, and locating them in the system are given.

"Water Power Plant at Gösgen, Switzerland." *Schweizerische Bauzeitung*, January to May, 1920. Details are given of hydraulic construction with numerous illustrations. The development is located on the Aare at Gösgen, Switzerland and has a total rating of 45,000 h. p.

"Hydroelectric Power Station at the Great Lake, Tasmania." London *Engineer*, July 9, 1920. An interesting scheme of speed control of water wheels is described for which it is claimed the advantages of both needle and deflector regulation are secured.

"Pelton Wheel Reconstruction," by Percy Pitman. London *Engineering*, June 25, 1920. Structural changes in Pelton water wheels are described, first, to replace defective and broken buckets which were becoming a source of danger and, second, to economize water by putting on buckets of a more modern and efficient type. It is reported that the efficiency was improved about 5 per cent by these changes.

"Niagara Falls 100,000-H. P. Development," by John L. Harper. *Electrical World*, September 18, 1920. Details of the general engineering problems involved are given, together with comments by N. R. Gibson in hydraulic design and efficiency of units in plant, comments by L. S. Berin Bernstein of effect of loading on construction of substructures and main features of plant operation by George R. Shepard.

"Centralizing Power Plant Maintenance," by W. C. D. Eglin and F. C. Ralston. *Electrical World*, September, 25, 1920. The author points out that by separating maintenance of plant equipment from operation uniform standards of work can be established and a group of repair specialists developed. The plan of handling maintenance work in centralized shops is shown in organization charts listing the personnel of the maintenance sections and showing their relations to the other groups comprising a station operation division. The system outlined is used in maintenance work in the generating stations of the Philadelphia Electric Company.

"Analyzing Maintenance Costs." *Electrical World*, September 25, 1920. This article shows the relationships of the age of equipment to energy output and shows that electrical apparatus is far less expensive to repair than steam equipment. Data are also given showing total repairs to be virtually proportional to plant rating. Maintenance costs of steam plant equipment for 1918 to 1920 in a station having a rating varying from 43,000 kv-a. to 63,000 kv-a. are given.

"High Economy in Small Steam Plants," by E. H. Tenney. *Electrical World*, September 25, 1920. The author gives results of experience in operating 28 plants containing one to three boilers. The causes of low efficiency are reviewed and means suggested for preventing, detecting and correcting operating conditions.

"Springdale Station of West Penn Power Company," by G. G. Bell. *Electrical World*, September 25, 1920. Details are given of the design of a steam plant with an ultimate rating of 300,000 kw. The station is located at a coal mine and coal is delivered to the bunkers direct from a mine tipple. Part 2 of this article describes electrical and operating features.

"Developments in Power Plants and Generating Stations," by Alfred Still. *Electrical Review*, August 21, 1920. The author gives general tendencies in power station design, both hydroelectric and steam electric.

"Electrical Features of Niagara Falls Power Station," by J. Allen Johnson. *Electrical World*, October 23, 1920. The

author points out that to insure reliability of service and simplicity of operation each 32,500-kv-a. generator in the Niagara Falls 100,000 h. p. Extension has been dealt with as a separate unit. Features of control are outlined.

"Power Station Designs." *Beama*, August, 1920. This subject is discussed under the following division: Drive of auxiliaries, maintenance of efficiency, condensing plant, feed water system, guarantees and testing, and over-all thermal efficiency of power station.

"Dalmarnock Power Station." London *Electrician*, September 20, 1920. This is a new power plant erected on the River Clyde not far from Glasgow. The ultimate capacity is 150,000 h. p. Energy is stepped up and transmitted at 20,000 volts to substations over three-core split conductors and six-core type cables using the Merz-Hunter system of protection.

"Design of the New Canadian Niagara Power Project." *Engineering News-Record*, October 14, 1920. The article gives fundamentals which govern the design of the hydroelectric installation of the Queenston Chippewa hydroelectric plant of the Hydroelectric Power Commission of Ontario.

"Electrical Equipment of the Super-Power Station at Golpa, Germany," by H. Probst, *Elektrotechnische Zeitschrift*, September 2, 1920. The output of this station was intended to be used for nitrogen fixation and to supply large nitric acid plants in the neighborhood with approximately 250,000,000 kw. hr. or one-third of the total output. The plant is located close to a lignite mine and is laid out for 64 steam boilers feeding eight A. E. G. turbines each coupled to one 6000-volt 50-cycle 22,000-kv-a. generator.

"Electrical Features of Springdale Plant of West Penn Power Company," by George S. Humphrey, *Electrical World*, December 4, 1920. The author describes the considerations in laying out this station to be operated at high power factor and the use of temperature detectors in generators and transformers, flexible scheme of supply for auxiliaries and balanced relay protection. Part 2 of this article (*Electrical World*, December 11, 1920) dealt with physical arrangement of equipment, balanced relays to protect generators and transformers and methods to indicate total station loads.

"Interconnection of Power Systems," by Harold W. Smith, *Electrical Journal*, November, 1920. The author deals with the important considerations in planning for interconnection of power systems and covers the following points: Selection of switching equipment, tie lines having ample synchronizing power to hold the systems in parallel; relay protection system; voltage conditions with regard to the flow of reactive current.

"Safety-First Methods of a Big Power Plant," *Power*, April 19, 1921. Rules for protecting employes of the United Electric Light & Power Company, New York City against mechanical and electrical dangers.

"Coal Handling Methods at New Baltimore Station," *Electrical World*, Jan. 15 and 29, 1921. Details of how coal is received and handled in a 140,000-kw. station and the method of dividing the load with large hydroelectric plant. Generator fire protection and the welding of steam piping.

"Switchgear in Modern Power Station," by R. A. R. Bolton, *English Electric Journal*, October, 1920. Arrangement of circuits and typical connections with comments on the use of current limiting reactors to reduce effects of short-circuit currents.

"Australian Steam Station of 125,000-Kw. Rating," *Electrical World*, Feb. 19, 1921. Design of a plant located in coal field where coal can be secured at cost of 50 cents per ton. All electrical equipment located out of doors.

"Hydroelectric Station of 50,000-Kw. Rating Built in 15 Months," by R. C. Starr, *Electrical World*, Feb. 26 and March 19, 1921. Construction and design for Kerckhoff station of San Joaquin Light and Power Corporation at Fresno, Cal. Considerations that influenced layout of equipment.

"Development of 450,000 Kv-a. on Pit River in California," by A. H. Markwart, *Electrical World*, March 12, 1921. Plans for construction of five stations utilizing 2070 ft. drop in Pit River. Units of 35,000 kv-a. rating to serve 220,000-volt transmission line.

"50,000-H. P. Waterwheels for 500,000-H. P. Plant," by E. T. J. Brandon, *Electrical World*, March 20, 1921. Layout of equipment for Queenston-Chippewa station of Hydro-Electric Power Commission of Ontario employing 50,000-h. p. turbines under a head of 305 ft.

"Colfax Station at Mouth of Coal Mine," *Electrical World*, April 2 and 16, 1921; *Power*, April 5, May 3, and May 24, 1921. Features of Duquesne Light Company's Colfax station design incorporated to attain high economy and reliability of operation. Details of initial installation of 60,000 kw. for a plant of 300,000 ultimate rating. Three-element compound 60,000-kw. turbo generators are installed and provided for. Duplication of circuits and equipment and arrangements to prevent spreading of troubles that may occur.

"New Type of Switch House to Prevent Bus Short Circuits," by B. C. Jamieson, *Electrical World*, April 2, 1921. Arrangement of New Calumet station of Commonwealth Edison Company with details of wide separation of bus phases to preclude interphase short circuits. Use of current limiting reactors to exclude outside disturbances.

"Plants of Chilean Exploration Company," by M. Neustatter, *Elektrotechnische Zeitschrift*, Jan. 6, 13, and 20, 1921. Detailed illustrated article on station layout and equipment built by Siemens-Schuckert in Berlin for producing electrolytic pure copper from ores in Chile. Power station is rated at 40,000 kv-a. Four 12,500-kw. steam turbines drive 9000-kw., 0.9-power factor, 5000-volt, 50-cycle, 1500-rev. per min. generators and receive steam from 16 B & W oil fired boilers. Descriptions of station electrical layout and transformer station are given, with wiring diagrams.

"Output of Systems Exceeding 100,000,000-Kw-Hr. in 1920," *Electrical World*, April 23, 1921. Peak load, date of peak and output for years 1920, 1919, 1918 and 1917 of 71 central station systems and 9 electric railway companies. Also tabulation of energy generated and purchased and that used for light, power and railways.

"Delaware Station of Philadelphia Electric Company," *Electrical World*, May 21, 1921. Factors taken into consideration in laying out a 180,000 kw. station on limited space at a time when steel was difficult to procure. Among the mechanical features discussed are the coal and ash handling facilities, unusual furnace design, facilities for converting to oil or powdered coal operation and the selection of auxiliaries.

B — Prime Movers and Generator Design and Operation

"Designs of Large Vertical Alternating-Current Waterwheel-Driven Generators," by M. C. Olson, *General Electric Review*, November, 1919. The author calls attention to some of the special features that must be considered in the mechanical and electrical design of large hydroelectric generators.

"Spring Thrust Bearing and Cooling Coils on Larger Vertical Generators," by T. W. Gordon, *General Electric Review*, November, 1919. The author states that for many years one of the limiting features of large vertical machines was the need of a simple thrust bearing.

"Features of Design in Large Hydraulic Turbine," by F. H. Rogers, *General Electric Review*, November, 1919. The author analyzes problems encountered in designing wheels of high efficiency for both low and high head applications. He calls attention to conditions under which certain losses become sufficiently important to warrant considerable effort to minimize them.

"Failures of Turbo Generators and Suggestions for Improvement," by J. Shephard, London *Electrician*, January 16 and 23, 1920. In the opinion of the author failures may be roughly

classified under (1) mechanical weakness, (2) electrical weakness, (3) heating and fire risks, (4) ventilating difficulties. An analysis of these failures is presented.

"Alternators Rated at 22,000 Kv-a. for Glomfjord," by J. Wennerberg, *Teknisk Tidskrift Elektroteknik*, November, 1919. This article gives drawings and pictures of two large three-phase generators built for the Norwegian Government's plant at Glomfjord, Sweden. These are rated at 20,000 kv-a. with a continuous overload capacity of 22,000 kv-a. and are the largest water turbine driven generators built in Europe.

"Effects of Short Circuits on Power House Equipment," by E. G. Merrick, *General Electric Review*, November, 1919. The author deals particularly with the electromagnetic stresses and abnormal temperatures developed in power house equipment resulting from short circuits.

"Mechanical Design of Large Turbo Generators," by M. A, Savage, *General Electric Review*, February, 1920. The author deals with high speeds and increased stresses in the construction of rotors and the ventilation of the modern turbo generator.

"Optimist's View of Turbine Development," by Richard H. Rice, *Electrical World*, April 17, 1920. Abstract of an address by Mr. Rice before the Boston section of the A. I. E. E. and A. S. M. E. in which he showed that turbine troubles were due chiefly to manufacturing conditions during the war.

"Ventilation of Steam Turbine Generators," by George Monson, London *Electricity*, March 12, 1920. The article reviews the development of forced air ventilation for cooling large generators and describes the modern closed air circuit with humidifying equipment and air dryers under the generator foundation.

"Short-Circuit tests on a 10,000-kw. Turbine Alternator," by E. S. Henningsen, *General Electric Review*, March, 1920. Data are given covering a series of tests on the performance of alternators having smooth-core rotors under short circuit.

"Huge Induction Regulator Installation," by Raymond Bailey, *Electrical World*, June 12, 1920. The author points out that in order to work transmission lines at maximum load the Philadelphia Electric Company has installed out-of-doors two 1750-kv-a., three-phase regulators and gives the conditions under which they operate. He presents a chart which shows how transmission line characteristics were determined.

"Electric Drive for Station Auxiliaries," by E. E. George, *Electrical World*, June 12, 1920. The author takes up the advantages of electric auxiliaries and the economies that accompany those advantages.

"Heating of Alternators and Induction Motors," by M. Baringolz, *L'Industrie Electrique*, November 25, December 10, and 25, 1919. The author presents a set of formulas permitting the calculation of the working temperature of stator copper, rotor iron and rotor copper in alternators and induction motors.

"Increasing Oil Circuit Breaker Capacity," by C. J. Hejja, *Electrical World*, July 10, 1920. The author gives details of a study on a standard oil circuit breaker with a view of determining the extent to which the rupturing capacity at short circuit of switching units in present use may be increased in order to avoid, if possible, the expense of replacing them by units of larger capacity or of a different type. A breaker equipped with pressure vents, hollow contact rods and improved liquid for quenching the arch showed greatly increased rupturing capacity under test.

"Predetermination of the General Dimensions of Electrical Machinery," by H. de Pistoye, *Revue Generale del'Electricite*, January 24, 1920. This article contains a number of general theorems regarding the relations between output and certain general dimensions, such as rotor diameter, iron legnth, width of air gap, speed, etc. A general formula is derived which shows the most economical relation of diameter to axial length for rotating machinery.

"Grounding of Electric Machinery and Installations," by J. Damien, *Revue Generale del'Electricite*, January 24, 1920. The author cites the French rules regarding grounding of electrical installations and criticizes their vagueness in wording. Advantages and disadvantages of different methods of grounding are discussed and some practical suggestions given.

"Governor Adjustment for Efficient Parallel Operation," by F. Oppenheimer, *Electrical World*, July 31, 1920. The author presents speed load curves of prime movers with various governor adjustments and gives details of the method used in adjusting the governors in the plant of the Pennsylvania Water and Power Company.

"Present Tendencies in Turbo Alternator Design," by J. Shepherd, London *Electrician*, July 2, 1920. The writer deals particularly with the problem of ventilating and water-cooling of turbo alternators. He also takes up the proper insulating of coils and the danger to coils of vibration.

"Selection of Oil Circuit Breakers," by W. A. Coates, London *Electrician*, July 2, 1920. The writer discusses the rating of oil circuit breakers with reference to breaker capacity as defined by the British Engineering Standards Association. He points out the advantage in having graphic methods of determining short circuit current values in networks and shows a chart devised for such use.

"Temperatures in Large Alternating-Current Generators," by W. J. Foster, *General Electric Review*, July, 1920. The author calls attention to certain advantages that would be derived in taking the air directly from the room and passing it away to some point in the building remote from the machines or out of doors.

"Features of 37,500-H. P. Water Turbine," *Electrical World*, October 2, 1920. In this article comments are presented by W. M. White on water wheel and generator considered as a homogeneous unit in the 100,000-h. p. extension to the plant of the Niagara Falls Power Company. Louis F. Moody discusses the design of waterwheels for generators of different makes.

"Factors Determining Generator Design," *Electrical World*, October 16, 1920. Comments by F. D. Newbury on the design of generators used in the new extension of the Niagara Falls Power Company together with comments by R. B. Williamson and W. J. Foster on designs furnished by the Allis Chalmers Company and the General Electric Company respectively.

"Repair and Inspection of Hydraulic Turbines," by L. W. Wyss, *Electrical World*, November 27, 1920. Practical information is given on taking machines out of service together with points to be observed during inspection.

"Oil Switches for Large Electrical Power Systems," London *Engineer*, September 3, 1920. Short-circuit characteristics of alternators and speed of oil switch opening with units of extremely large size are discussed in this paper.

"Continental Switch Gears," by W. A. Coates, *Beama*, October, 1920. The author deals with circuit breakers and electrical layout common to European practise.

"Recent Development in Turbo Alternators," by F. D. Newbury, *Electrical World*, January 17, 1920. The author comments on the increase in ratings from 1913 to 1917 and the tendency in steam turbine-generator construction and operation.

"Investigation of Water-Air Radiators for Cooling Generators and Motors," by H. G. Reist and E. H. Freiburghouse, *General Electric Review*, February, 1920. The authors point out that in the case of electrically driven ships the usual method of washing the ventilating air for turbo-generator units cannot be applied on account of the space limitations on shipboard. The plan of circulating salt water through a radiator much on the order of the automobile radiator and cooling the hot ventilating air by this means, has been investigated by the authors. A number of data and curves is given to show the advantages of this method where space is limited.

"Present Status of Large Turbo Generators," by Dr. Louis Bell, *Electrical World*, January 17, 1920. The author deals

with the size of station and the requirements from the standpoint of economy and simplicity in station design and operation. The speed stresses are touched upon and the advantages and disadvantages of multiple-stage generating units.

"Some Recent Developments in Large Steam Turbine Practise," by K. Baumann, April 7, 1921, *Journal* Institution of Electrical Engineers, London. The author reviews in great detail developments of steam turbine design and construction in Europe and America since 1912 to date and also deals with a new design which embodies a multi-exhaust system where the steam in the last stage passes partly into impulse blading and partly through reaction blading with claim of greater capacity and efficiency with no appreciable increase in over-all dimensions of single barrel turbines of the Curtis type.

"Temperature Limits of Large Alternators," by G. A. Juhlin. *London Electrician*, Jan. 28, 1921. The possibility of increasing temperature limits in alternators using class B insulation is discussed with list data for breakdown voltage of mica wrapped in copper bars after heating for 7000 hours at 190 deg. cent.

"The Modern Hydraulic Turbine," by Frank H. Rogers and Lewis F. Moody, *Journal of Philadelphia Engineers Club*, March, 1921. Two articles on the hydraulic turbine from standpoints of modern requirements; tests of models, special features of designs; and requirements of larger stations. Mr. Moody reviews the turbine's evolution and describes new types of high speed runners.

"Manufacture of High-Voltage Alternating-Current Windings," by W. Zederbohm. *Siemens Zeitschrift*. Illustrated description of high voltage motor, generator and regular windings developed during last 20 years. Asphalt treatment and inclosing of coils in sleeves of "Mikanite" standardized by Siemens-Schuchert Works.

"The Gas Turbine," London *Engineer*, Feb. 11, 1921. Tests at works of Thyssen & Company on 500-h. p. gas turbine invented by H. Holzwarth and built in 1914.

C — Boiler Plant Design and Operation

"What the Adoption of Higher Steam Pressure Will Mean," by F. R. Parsons. London *Electrician*, January 2, 1920. The writer considers the effect of higher steam pressures on standard boiler design, on the material used and on reciprocating engines.

"Extension to L Street Station, Boston," by Charles H. Bromley. *Power*, January 27, 1920. Boiler room provided for convenience and economy. 30,000-kw. single-cylinder impulse turbine installed.

"Electrically Heated Boilers and Heat Storage." London *Engineering*, February 6, 1920. Details are given for the heating of water by electricity where water power is inexpensive. Attention is called to tests on two electricity boilers in Switzerland in which it is said that 90 per cent efficiency was obtained. Several makes of boilers equipped for electrical heating (mostly of Swiss origin) are described.

"Sluicing Ashes Shows Low Cost," by A. W. Morgan. *Electrical World*, July 3, 1920. The method used in the new Denver station of the Denver Gas & Electric Light Company is explained, which shows the handling cost of 16.4 cents per ton of ashes or about 2 cents per ton of coal fired.

"Preparing Pittsburgh District Waters for Boilers." *Power Plant Engineering*, August 15, 1920. Reference is made to the water of the Monongahela River where water pumped from mines into the river is highly charged with sulphates and the industrial pickling and by-product coke plants which line the river banks have a contaminating refuse water which is discharged into it. Efficient testing and treating required for this water are described.

"Surface Condenser Maintenance," by R. J. T. Wood, *Electrical World*, September 25, 1920. The author shows by illustrations the composition and structure of tubes. He points out that many steam station troubles are directly traceable to salt-water leakage in condensers where plants are near the seashore and discusses the over-all plant economy when adequate condenser maintenance is not attended to. Reference is made to maintenance work in the plant of the Southern California Edison Company at Long Beach and Rodondo Beach.

"Steam Plant Metering Practise," by Robert E. Dillon. *Electrical World*., September 25, 1920. The author points out that the checking of losses in the boiler room and the turbine room of large central stations by the aid of records from instruments is passing through the stage today which was passed by the electrical end of the station years ago. He refers to the types of instruments and records which are essential to efficient steam plant operation.

"Emmet Mercury Boiler." *Power*, August 3, 1920. Details are given for the construction of a mercury boiler and turbine which has been developed by W. L. R. Emmet and makes use of high boiling point of mercury and its condensing points at 28 inches vacuum and 465 deg. fahr. The heat given out by the condensing mercury vapor makes steam of the cooling water and this steam may be used to drive another turbine or for any other purpose for which steam may be required. The experimental equipment has been in operation with over 1000 kw. load on an electric turbine and its operation showed that the economies predicted were fully realized. Mr. Emmet believes that with an increase of 15 per cent in the amount of fuel used the same amount of steam can be supplied to the turbines as under present conditions and a mercury turbine will generate power equal to about 66 per cent of the power generated by steam turbines.

"Factors in the Design of Large Boiler Plants," by J. G. Rollow. *Electrical Review*, August 21, 1920. The author discusses the principal factors affecting equipment of boiler plants of large capacity.

"Selection of Steam Plant Meters," by J. W. Andree. *Electrical World*, November 20, 1920. The author divides metering of apparatus into classes necessary for safe operation, for good operation, and for checking results and gives a list of devices included in each of these groups. He also shows that the proper use of correct meters will greatly improve economy. Reference is made to the results which are being secured in the Long Beach Steam Station of the Southern California Edison Company.

"Economies to be Expected of a Super-Station," by John A. Stevens. *Power*, June 1, 1920. Table giving power costs for 100,000-kw. turbine station with different priced coal.

"Remodelling Stokers and Furnaces," by T. A. Marsh, *Electrical World*, Jan. 22, 1921. How boiler ratings were increased 39 per cent by enlarging grate areas and improving arch designs.

"Redesigned Stirling Boilers," *Electrical World*, April 23, 1921 and *Power*, April 19, 1921. Details of reclassification and standardization to simplify tube lengths, drum locations and other fundamental elements.

D — Fuel and Combustion Studies

"Burning Low-Grade Coals of Montana and Wyoming," by E. H. Bull. *Electrical World*, January 10, 1920. The author gives test data for fuels that have heretofore given operating men much difficulty and shows that proper furnace design will solve the combustion problem associated with the burning of such fuel.

"Pulverized Coal in Central Stations," by John Anderson. *Electrical World*, March 13, 1920. Data given on tests of five 468-h. p. boilers using pulverized coal in the Oneida Street power station of the Milwaukee Electric Railway and Light Company.

"Fusibility of the Coal Ash from Eastern Coal," by Messrs. Selvig, Brown and Fieldner. *Coal Age* January 22-29, 1920. Tables are given showing the fusing temperatures of the ash of coal mined in certain sections of the eastern coal regions,

the sections chosen being parts of Ohio, Virginia, Kentucky, Maryland, Tennessee, and Alabama.

"Burning Oil with Mechanical Atomizers," by Robert Sibley and C. H. Delany. *Electrical World*, March 27, 1920. Operating details are given for the mechanical atomizing oil burner or pressure-jet burner with best operating pressure and temperatures outlined.

"Handling Coal by Using Belt Conveyors." *Electrical World*, April 10, 1920. Details are given for handling coal in modern plants with examples from installations in the Middle West and the East.

"How Bituminous Coal Can Be Safely Stored," by H. H. Stoek. *Coal Age*, March 18, 1920. A careful discussion of the best methods of storing various kinds of bituminous coal are given with special reference to fire risk.

"Burning Low Grade Coals of the Southwest," by W. M. Park. *Electrical World*, April 24, 1920. Operating and test results are given with chain-grate settings of different types with recommendations for using the fuel available in the Southwest.

"Pulverized Coal." *Electrical Times*, (London), May 20, 1920. Deals with changes necessary in water tube boilers for the application of powdered fuel indicating that the front of a furnace may be extended and converted into a combustion chamber.

"Storing of Coal for Central Stations," by H. H. Stoek. *Electrical World*, July 31, 1920. The author points out that the experience of recent years has emphasized the necessity for storing of coal and that coal should be of uniform size and free from dust, but with proper care, run of the mine may be stored. Details of various methods used are outlined, with a discussion of spontaneous combustion and the importance of size of coal in storage. Precautions to be taken in storing coal are also given.

"Unusual Efficiencies with Oil Fuel," by Joseph Pope and Frank G. Philo. *Electrical World*, October 9, 1920. The authors give details of the arrangement for using fuel oil with mechanical atomizers in the plants of the Savannah (Georgia) Electric Company and the Blackstone Valley Gas and Electric Company of Pawtucket, R. I. Details of tests on the new installations are also given.

"How the Coal Situation has Affected Central Stations in the last Six Years." *Electrical World*, October 16, 1920. A tabulation is presented which gives the reports from 54 central stations showing the amount of storage, kinds of coal purchased, the prices paid, and the pounds of coal used per kilowatt hour.

"Mechanical Oil Atomizer Efficient at 320 Per Cent Boiler Rating." *Electrical World*, October 16, 1920. Details of tests made by the Babcock and Wilcox Company on a 450-h. p. boiler fired by mechanically atomizing oil burners are given by Darrah Corbet.

"Remodeling Ignition Arches," by T. A. Marsh. *Electrical World*, October 23, 1920. The author deals with the importance of properly proportioning ignition arches to combustion rates and points out that the desired stoker dimensions influence ignition arch design on which capacity, efficiency, responsiveness, and fuel range depend.

"Efficient Handling of Fuel Oil." *Power*, January 11, 1921 to March 8, 1921. Storing, and feeding to furnaces.

"Pulverized Coal Under Central Station Boilers," by John Anderson. *Power*, March 2, 1920. Methods of applying equipment, and facts concerning operation.

"Superpower Plant for Utilization of Peat," by F. Bartel. *Elektrotechnische Zeitschrift*, Nov. 4, 11, 25, 1920. Design of a 120,000 steam-electric station to burn peat bog. The total production is estimated at 400,000,000 kw-hr. with a peat consumption of 920,000 tons per year. Details for storing the fuel are given.

"Ultimate Boiler Capacity Limited by Fuel Conditions," by Joseph Harrington. *Electrical Review*, March 26, 1921. Size and characteristics of fuel and rates of combustion in furnaces. Fusing temperature of ash and its effect on rates of combustion on grates and in fuel beds.

"Powdered-Coal Firing for Power Stations," by Friedrich Munzinger. *Elektrotechnische Zeitschrift*, Feb. 3, 1921. Details of different systems for pulverizing coal, feeding it to boilers, and burner construction for large station units.

ELECTRICAL MACHINERY COMMITTEE

To the Board of Directors:

In its endeavor to assist in advancing the art in the field coming within its scope, and in recording progress made therein, the Committee on Electrical Machinery has cooperated with the Standards Committee, the Meetings and Papers Committee and the Library Board of the A. I. E. E.

For some time it has had under consideration certain proposed changes in the Standardization Rules relating to high-potential testing in order to overcome the failure of the present rules to impose any test between adjacent coils in any circuit of any phase; any test between phase windings where the highest potential difference exists when the machine is operating, and to overcome the unknown stresses imposed at certain points due to the capacity effects in large machines.

The Committee has reviewed for the Papers Committee all the papers submitted for presentation before the A. I. E. E., or for publication in the JOURNAL, that deal in any way with electrical machinery. Through the medium of papers solicited the Committee has aimed to place on record the advances in the art as indicated in design and theory as well as in the construction of the great power plants on sea and on land. It has arranged for the preparation and presentation of a paper by Mr. E. S. Henningson on "The Application of Synchronous Motors to the Propulsion of Cargo Boats"; a paper by Mr. John L. Harper on "Extension to Plant No. 3 at Niagara Falls," and one by Mr. William M. White on "Hydraulic Turbine Development." These three papers will be read at this Convention.

For the purpose of determining in what way the Engineering Societies Library now supplies the wants of the Electrical Machinery Committee, or of persons interested in electrical machinery, a study was made of the conditions in the Library from the point of view, not of librarians, but of persons desiring to obtain information concerning the theory, design, construction and operation of electrical and allied machinery. This study disclosed an unnecessarily unsatisfactory condition in the facilities placed at the disposal of engineers interested in, and under necessity for, investigating new phenomena and for solving new problems, and these facts have been laid before the Library Board of the A. I. E. E.

In the work undertaken by the Electrical Machinery Committee, the chairman has had the unanimous and enthusiastic support of the members of the Committee.

B. A. BEHREND, *Chairman.*

(*To be continued*)

Magnetic Properties of Compressed Powdered Iron

BY BUCKNER SPEED and G. W. ELMEN

Research Laboratories of the American Telephone & Telegraph Company and the Western Electric Company, Inc.,

This paper describes a new magnetic material which is peculiarly suited to the construction of cores in small inductance coils and transformers such as are used in a telephone plant. The requirements which were to be met involved a core material which should have a constant permeability, a small hysteresis loss, and a small eddy current loss within the range of magnetizing forces and frequencies which are met in telephonic operation. The material which was developed to meet these requirements is formed by fine grains of powdered iron, insulated and compressed. There are described the circumstances and experiments which led to this development and also the method of commercial production. Tables and curves are given showing the magnetic, electrical, and mechanical properties of the material.

THE DEVELOPMENT of a successful method of compressing insulated grains of iron to produce a material magnetically and electrically suited for use in the telephone plant has had a determining effect upon recent progress in methods of loading and compositing telephone lines as well as upon the introduction of carrier current systems of multiplex telephony. It is the purpose of the present paper to discuss briefly the circumstances and experiments which led to this development and to describe the method of commercial production and the magnetic characteristics of the finished material.

The most important use of this material is in the construction of the cores of the loading coils which are introduced at regular intervals to increase the inductance of a telephone circuit.[1] It is also used in the cores of inductance elements in filters for carrier current systems,[2] and in those of reactance coils and transformers for radio telephone circuits. Coils for use in these circuits have to meet requirements which are in general quite different from those of other circuits, as, for example, power transmission circuits.

In telephone-transmission lines, for example, the inductance of the loading coils must remain constant throughout the entire range of intensities of the currents which are employed in the telephone plant. The amplitude of the currents to which a given coil is subjected may vary as much as one hundredfold.

The first requirement for the magnetic core-material of a loading coil, therefore, is that its permeability shall remain constant over the range of magnetizing force corresponding to the normal range of telephone currents.

The second requirement arises from the simultaneous use of circuits for telephone and telegraph transmission. It is necessary that the variation in the effective resistance of the coil, which is caused by hysteresis[3] and occurs when two currents of different frequencies and amplitudes are superposed, shall be so small that what is known as "flutter" in the transmitted speech shall not be objectionable.

The third requirement concerns the effective resistance which is introduced into the telephone circuit because of hysteresis and eddy-current losses in the core-material of the loading coil. It is required that the effective resistance due to these causes shall be small in order that the total resistance of the coil, including its copper loss, shall be small as compared to the resistance of a length of line conductor equal to the length of the loading section. Since the effects of hysteresis and eddy currents will depend upon both the frequency and the amplitude of the telephone currents, it is further evident that the constancy of loading coil operation requires that these losses shall be minimized.

These requirements were met successfully in the early development of loading coils by the use of hard iron either in wire or in sheet form. Cores of hard-drawn wire were developed and adopted by the engineers of the American Telephone & Telegraph Company and were used successfully until the core-material herein described was put on a production basis. Two advantages pertain to the use of hard material in preference to soft. In the hard material the variation in permeability for a large range of magnetizing forces is less than in the soft iron. This is especially true at the initial part of the magnetization curve where, for a very large range of magnetizing force, the permeability of the hard material is constant. The second advantage is due to the fact that over this range in which the permeability is constant the hysteresis loss per unit of volume is less in the hard than it is in the soft material for the same flux density.

In order to take advantage of the constancy in permeability and the low hysteresis loss at small magnetizing forces[4], the coils were designed so that for the range of speech currents the magnetizing force corresponded to that of the initial part of the magnetization curve. In a standard design of coil the magnetizing force corresponding to an average telephone current of one milliampere is of the order of 0.01 gauss.

In addition to the magnetic requirements for the core-material, its electrical resistivity is also of great importance. This is due to the fact that the important frequency of the speech currents as usually assumed,

To be presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

1. B. Gherardi. "Commercial Loading of Telephone Circuits in the Bell System." TRANS. A. I. E. E. 1911, Vol. XXX, p. 1743.

2. Colpitts and Blackwell. "Carrier Current Telephony and Telegraphy," JOURNAL A. I. E. E., Feb. 1921.

3. Fondiller and Martin. "Hysteresis Effects with Varying, Superposed Magnetizing Forces." JOURNAL A. I. E. E. Feb. 1921.

4. In this paper the term "small magnetizing force" is used to indicate forces below 0.1 gauss.

is approximately 800 cycles per second and unless the resistivity of the material is very high or the core material is very finely subdivided, the losses caused by the eddy currents are excessive. In order to reduce the effective resistance caused by these losses it was found necessary to employ iron wire drawn down to a diameter of 0.004 in. and, in addition, to insulate the separate convolutions of the contiguously-wound core. Two types of wire were established as standard for loading coils, classified according to the permeability at low magnetizing forces. For one type the permeability is 95, and for the other, 65. The difference in permeability between the two types is the result of a difference in the process of drawing the wire, that of lower permeability being drawn a greater number of passes without annealing.

Cores constructed in the above manner were used for a number of years. With the introduction of repeaters, and especially on composited and phantomed circuits, the requirements as to stability and constancy in the physical characteristics and operation of loading coils became more severe. To meet these conditions it was found necessary to introduce air gaps[5] at right angles to the flux path in the core of the loading coil. The introduction of such air gaps was conditioned by certain other requirements, specifically for example, by the requirement as to a balanced-winding arrangement in coils designed for phantom circuits where an absence of balance between the several windings would introduce stray magnetic fields. In telephone practise parallel circuits are loaded at a common point and the coils are either adjacent on a loading pole fixture, or are assembled in a common case. Under the latter condition, if stray magnetic fields surround the cores of such coils there would be introduced an interference between parallel telephone circuits which is ordinarily spoken of as "cross-talk." For this reason the air gaps which are introduced into the core of the loading coil have to be spaced symmetrically with respect to the balanced-winding arrangement.

The production of this hard-drawn wire requires the use of diamond dies and these were imported from Europe. Early during the war importation became impossible and our supply of hard-drawn wire was thus seriously curtailed. Fortunately the development of the powdered-iron cores while not completed had reached the stage where the material could be quickly put into commercial production to meet the demand for core material.

In order to be useful as a substitute for fine iron wire, a magnetic material must have the following general properties: (1) the permeability at low magnetizing forces must be between 20 and 100, (2) the material must be very finely divided in a direction at right angles to the magnetizing force in order to decrease the effective resistance caused by the eddy currents, (3) the hysteresis loss must be low, and (4) the cost of manufacture into core form must compare favorably with that of iron-wire cores.

From a preliminary investigation the most promising possibilities seemed to lie in the direction of using finely-divided iron powder, each particle sufficiently insulated to eliminate eddy currents between contiguous particles. The general idea of using this kind of material for telephone-magnet cores was old. In 1887 Heaviside[6] described cores made from finely divided iron and insulated with wax. Coils with such cores were tested on an inductance bridge at telephone frequencies for the purpose of determining to what extent the effective resistance caused by the eddy currents had been eliminated. The results indicated that the subdivision was very effective in eliminating eddy-current loss.

About the same time others[7], notably Fritts, suggested the use of finely divided iron for pole pieces and armatures in dynamos and motors and for the core of other electromagnets. Interest along this line then subsided, probably because more satisfactory results could be obtained with laminated iron.

About 1900 the interest in the use of finely divided iron for a core material was revived by the introduction of loading coils. For the cores of loading coils Dolezalek[8] suggested the use of finely divided iron in very much the same form as Heaviside had previously employed it for telephone magnets.

A constructive suggestion was made in 1901 by F. A. Pickernell of the Engineering Department of the American Telephone and Telegraph Company. He advocated the use of finely divided magnetic oxide of iron or iron powder as a suitable material for loading-coil cores. The possibility of using iron oxide was investigated by the Telephone Company engineers and actual methods of production [9] were developed and loading coils with cores of this material were constructed. Toroidal cores were made by using iron laminations or iron tape. After the cores were formed they were subjected to an oxidizing process which transformed the iron into magnetic oxide of iron (Fe_3O_4). The results obtained on these coils gave enough promise to indicate that it would be possible to produce cores in this way. As hard-drawn iron wire cores were developed about the same time and as the energy losses of these cores were considerably less the development work was discontinued.

The magnetic properties of finely divided iron have also been studied by a number of investigators[10] but all the permeabilities which they record are for values of magnetizing force much larger than those with

5. Fondiller and Shaw. U. S. Patent No. 1, 289, 941. 1918.

6. *The Electrician*, Feb. 11, 1887, p. 302, also Elect. Papers Vol. II, page 398, 1894.

7. See bibliography at the end of the paper.

8. U. S. Patent No. 716206, 1902.

9. Lee and Colpitts, U. S. Patents No. 705935 and 705936. 1902.

10. See bibliography at the end of the paper.

which we are concerned in telephony. In all of the investigations, with the exception of Benedicks[11], the material was either entirely uncompressed or was very slightly tamped. The permeabilities recorded by these experimenters are less than 10. Benedicks compressed his material by continued tamping, and the permeability of his core, at the magnetizing force of 143 gausses, was 90 as compared with a permeability of 143 for solid iron at the same magnetizing force. Benedicks, however, was interested only in direct-current magnetizations, and the material which he produced was of no value at high frequencies as the particles of iron were not insulated.

There was nothing in the literature to indicate what permeabilities could be obtained at low magnetizing forces. It seemed, however, to one of the authors[12] that the use of powdered iron for core-materials had important possibilities. He concluded that if a pure finely divided iron powder could be insulated with a very tenacious insulation and compressed so that the specific gravity was nearly that of solid iron, it should be possible at low flux densities to obtain permeabilities of the order required for loading-coil cores.

Experimental Work

The experimental work, through which powdered-iron cores of commercially valuable properties were first obtained, could not be fairly stated unless we here made acknowledgment of the able assistance rendered by J. T. Butterfield and J. H. White. To W. Fondiller is due the designing and engineering of the loading coils embodying the compressed iron cores.

Early Experiments. Our earliest efforts were directed towards obtaining particles of finely divided iron each with a coating which would retain its insulating properties when a mass of them was compressed to a specific gravity of the order of that of solid iron. The iron powder used in the early experiments was powder reduced from iron oxide in hydrogen. This powder was mixed with a little water and slowly dried by heating it to a temperature between 100 and 150 deg. cent. until the particles had a coating of oxide on them. This oxide was mostly red oxide of iron although under certain conditions both the red and black oxide were present. After the oxide coating was obtained, the powder was mixed with a thin solution of shellac and dried while the mass was stirred to prevent caking. When dried, the insulated powder was put in a mold and pressed into rings from 1/8 to 1/4 in. thick, and with inside and outside diameters of 2 1/8 and 3 7/8 in., respectively.

Pressures. The pressing was first done with a press which developed a pressure of 100,000 pounds per square inch of surface of the rings. As this pressure did not seem high enough to obtain the required permeabilities, a press was obtained which, for the same surface, produced pressures up to 250,000 pounds per square inch. When the material was subjected to 200,000 pounds per square inch of surface cores were formed which had sufficiently high insulation between the particles and also at low magnetizing-forces a permeability[13] between 50 and 60, that is of the order required by a substitute in loading coils for the 95-permeability wire.

Insulation of the Particles. In addition to the method of insulating the particles described above, a number of other methods were attempted before the one now used commercially was adopted. In place of oxidizing and shellacking, some cores were made in which shellac only was used. Others were insulated with asphaltum compound dissolved in carbon tetrachloride, and the mixture stirred until the solvent evaporated. A number of different kinds of varnishes were also tried. In place of oxidizing the surface of the iron particles, there was also tried the method of chemically producing on the surfaces coatings of other compounds of iron. None of these methods gave as satisfactory results as the method used in our early experiments. This was due to the fact that if the insulation were made sufficiently thick to prevent the iron grain from cutting through it under pressure, it introduced too large air gaps in the magnetic circuit.

While investigating these possibilities, J. C. Woodruff[14] discovered that when a quantity of iron powder was rolled in a zinc-lined drum for a few hours and then insulated with a shellac solution the resulting product showed for corresponding permeabilities a higher specific resistance than had been obtained by any of the previous methods. Pursuing this further he found that if before applying the shellac he mixed the iron powder with flaked zinc, rolled the mixture in a drum for a few hours, and then removed the zinc by sieving, a very thin and tough insulation of the grains of iron was obtained which did not break down when the cores were compressed. As this is a very convenient method of insulating the material commercially, it was adopted and is being used in commercial production of powdered iron cores.

Production of Iron Powder. Next to the question of the possibility of using iron powder for making cores, the problem of obtaining a source of supply is important. In the early experimental work, as has already been stated, there was used iron reduced from the magnetic oxide by hydrogen. The two main objections to this material were the high cost of production and the fact that the reduced iron was very soft The latter is a serious defect, as has already been

11. *Journal of the Iron and Steel Inst.* Vol. I, p. 407, 1914.

12. B. Speed, U. S. Patent No. 1274952, 1918.

13. In determining permeability no correction is made in the flux density for the insulation and the air space. The cross-sectional area is assumed to be the measured cross-sectional area of the ring, and the permeability recorded is the total flux divided by the cross-section of the ring and the magnetizing force.

14. U. S. Patent No. 1,292,206, 1919.

pointed out, in case the material is to be used for cores in the highest grade of loading coils. The pressing of the iron powder introduces a considerable amount of mechanical hardness but is insufficient to give the material as good magnetic qualities as the 65-permeability iron wire. The introduction of other means of hardening the material, although possible, would increase the cost of production. When studying the question of obtaining a source of supply, one of the authors[15] concluded that if iron was deposited from a suitable electrolyte it could probably be ground to the required fineness and it would also have the additional quality of being a hard material. This method of producing iron powder would also be relatively inexpensive and the quality of the material could be controlled a great deal more readily than in other methods of production. Work was immediately started to investigate this possibility and the preliminary work was so encouraging that a good-sized experimental plant was installed.

Satisfactory material was obtained by electrolysis of a solution containing ferrous sulphate and chloride and ammonium sulphate using anodes of mild steel and cathodes of polished sheet steel, with current densities of about twelve amperes per square foot. The cathodes were removed when the deposit had reached a thickness of 1/8 to 1/4 in., and washed in hot water to remove the electrolyte.

The deposited iron was then stripped from the cathode sheets and broken up into pieces about an inch square. This material was next placed in a ball mill and ground until all of the material would pass through a sieve with 80 meshes to the linear inch. The ground iron then contained particles from the largest size passing through the sieve to the very finest flour. Sieve analysis showed that approximately 35 per cent to 50 per cent of this material would pass through a 200-mesh sieve. Unless the iron powder was to be annealed, it was now ready for the insulating process.

If annealed iron was desired, the powder was packed into cast-iron boxes and heated to about 850 deg. cent. and then allowed to cool slowly with the furnace. The material was then removed from the boxes. Because of a certain amount of sintering it was necessary again to break up the material into the original mesh by putting it through a rock crusher. By this process the iron was very readily reduced to its original fineness. The annealing process also purified the iron to a certain extent since the occluded hydrogen was liberated at a comparatively low temperature and reduced to pure iron the oxide which was present. This made the annealed iron purer than the unannealed.

This method of obtaining the supply of iron powder has been adopted commercially and a description of the commercial plant will be given later in this paper.

15. G. W. Elmen, U. S. Patents No. 1297126 and 1297127, 1919.

Magnet Cores. The present method of producing magnet cores from iron powder is as follows: The iron is deposited electrolytically, ground, sieved, insulated and pressed in dies at a pressure of 200,000 pounds per square inch of surface. The rings are pressed to a thickness of approximately 1/4 in., the inside and outside diameters depending on the design of the coil. After pressing, these rings are baked at a temperature of 125 deg. cent. to remove the moisture. The cores are constructed from these rings. Ordinarily several of the rings are stacked together to make a core and covered with insulating tape before the copper winding is put on.

The use of iron powder of the kind described lends itself very readily to the construction of cores having any desired permeability below 60 at low magnetizing forces. At the present time three standard types of core-material are commercially produced. These will be designated, for convenient reference, as grade A, grade B, and grade C. The order of designation does not imply the order of superiority in magnetic properties. The same pressure, 200,000 pounds per square inch, is used for all of these grades. Grade A consists of annealed and insulated iron-powder which has passed through a sieve with 80 meshes to the linear inch.

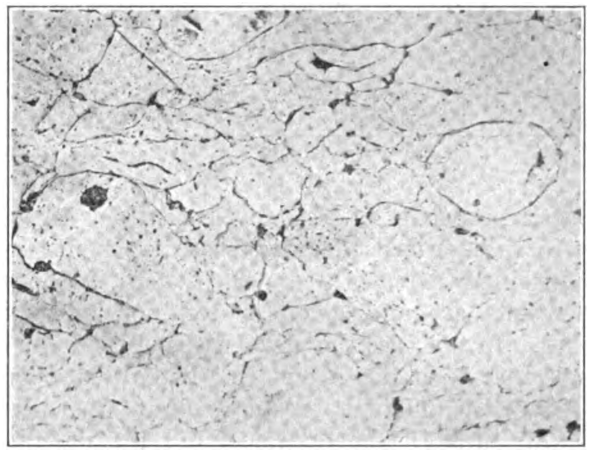

FIG. 1—MICROPHOTOGRAPH OF SURFACE OF GRADE A RING
Magneflcation 100 diam.

The permeability of this material at low flux densities is approximately 55. Grade B consists of material of the same mesh as grade A but is a mixture, 90 per cent unannealed and 10 per cent annealed. The permeability for the same magnetizing forces is approximately 35. Annealed iron is added in order to bring the permeability up to the desired value and also to add somewhat to the mechanical strength of the rings. Grade C is a mixture of the same proportions as grade B, but it passes through a sieve of 200 meshes per linear inch. The shellac insulation for grade C is also considerably heavier than for grades A and B. The permeability of grade C is approximately 25.

Fig. 1 is reproduced from a microphotograph of the surface of a grade A ring showing the distortion of

the iron grains and the thin walls of insulation separating them.

Figs. 2 and 3 show two sizes of rings and a coil in which part of the winding and core has been removed.

Electrical and Magnetic Properties

There will now be presented the results of tests under a large number of conditions, from which there may be obtained a very complete idea as to the electrical and

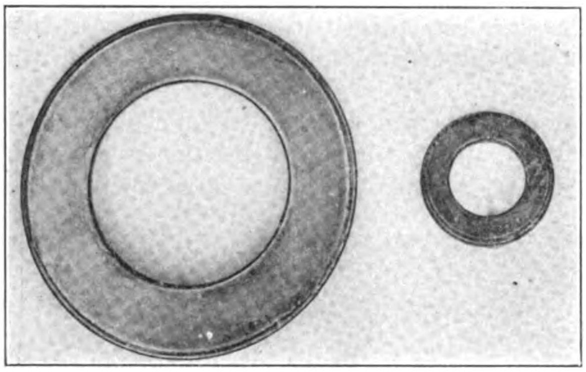

Fig. 2

magnetic properties of electrolytic iron powder. The tests to be described cover cores pressed from electrolytic iron-powder both annealed and unannealed. The results are also given of tests on uninsulated powder. In this case the powder was of the same fineness as that of grades A and B. There is also shown the effect of different pressures upon the physical constants of both the annealed and the unannealed iron-powder. The tables show also the specific gravity

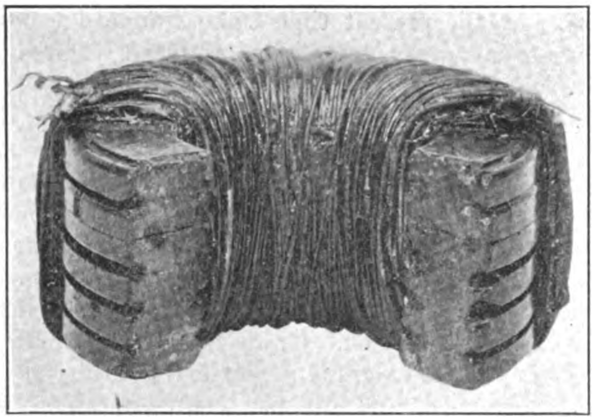

Fig. 3

and the tensile strength of some of the materials. It is to be noted that grades A, B and C are standard materials; the other materials for which values are given are recorded only for purposes of comparison.

Specific Gravity. The specific gravity for uninsulated iron powder, compressed with different pressures, is given in Fig. 4. The specific gravities for the grades A, B and C cores are given in Table I.

Tensile Strength. The mechanical strength of the rings is considerable and no difficulty is experienced in handling them in the general process of manufacturing cores. In Table I is recorded the load in pounds per square inch of cross-section necessary to disrupt the pressed rings under tension. The specific gravity of the rings is also given in this table.

TABLE I.

	Tensile Strength Pounds per sq. in.	Specific Gravity
Grade A rings	1375	7.1
Grade B rings	925	6.4
Grade C rings	375	6.0

Specific Resistance. In the measurement of specific resistance the current was led into core rings of the

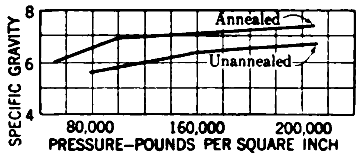

Fig. 4—Specific Gravity of Uninsulated Iron Powder Cores Compressed with Different Pressures

material by small clamps, placed diammetrically opposite one another, and thus dividing the ring into two equal current paths. The drop of potential was measured in different parts of the surfaces of the two halves of the ring. The clamps were then turned through 90 deg. and measurements were again made. The specific resistance of the compressed rings was calculated from the dimensions of the ring and the distance between the potential points. The specific resistance of the various types of iron powder use in these measurements are recorded in the same tables

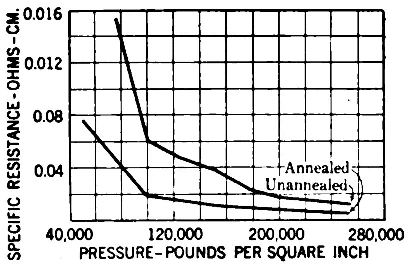

Fig. 5—Specific Resistance of Uninsulated Iron Powder Cores Compressed With Different Pressures

as the magnetic properties and in Fig. 5 is plotted the specific resistance for uninsulated powder compressed with different pressures.

Magnetic Properties. The magnetization curve and hysteresis loops for direct-current magnetization were measured with the ballistic galvanometer. From these measurements the permeability, the hysteresis loss (W_h), the hysteresis exponents (x), and the hysteresis coefficient (η) were computed. The data on various types of cores are tabulated in the following tables and in some instances are shown by typical graphs.

TABLE II
PROPERTIES OF ANNEALED UNINSULATED IRON POWDER CORES

Pressure lb. per sq. in.	Sp. gr.	Sp. Res. ohm-cm	H	B	μ	Coercive force	Remanence	W_h Ergs per cm³ per cycle	x	η
254,000	7.4	0.0007	57.4	13,650	238	5.5	5,780	24,350	1.705	0.002105
			24.7	10,460	425	4.9	5,060	14,300	1.715	0.001892
			16.8	8,490	505	4.5	4,300	10,000	1.730	0.001683
			8.14	4,060	500	2.95	1,960	2,910	1.780	0.001114
			2.57	514	200	0.52	112	57.5	2.005	0.000208
			0.70	105	150	0.09	8	2.0	2.295	0.0000460
203,000	7.3	0.0010	60.6	13,000	214	5.8	5,250	24,180	1.655	0.00370
			26.05	9,760	375	5.2	4,490	14,050	1.675	0.00300
			17.05	7,500	440	4.6	3,650	9,080	1.700	0.00239
			8.87	3,640	410	3.1	1,725	2,720	1.810	0.00953
			2.85	498	175	0.47	96	50.7	2.000	0.000232
			0.816	98	120	0.08	8	2.15	2.155	0.000103
152,000	7.1	0.0012	57.6	10,800	184	7.0	4,200	21,700	1.635	0.00568
			30.2	8,200	272	6.45	3,750	14,050	1.670	0.00402
			20.2	6,250	310	5.45	2,920	8,650	1.720	0.00264
			10.2	2,950	290	3.45	1,270	2,340	1.805	0.001265
			3.07	399	130	0.51	73	45.6	2.075	0.0001815
			0.943	99	105	0.08	7	1.67	2.795	0.00000437
101,600	7.0	0.0019	56.5	9,600	170	5.90	3,330	16,900	1.585	0.00826
			26.8	6,700	250	5.55	2,850	9,800	1.605	0.00687
			17.9	4,990	279	4.75	2,200	5,880	1.635	0.00536
			8.90	2,180	245	2.90	860	1 420	1.855	0.000897
			2.17	325	150	0.41	50	30.8	2.210	0.0000867
			1.10	99	90	0.07	7	1.55	3.005	0.000001555
50,700	6.1	0.0078	62.0	5,890	95	5.75	1,750	10,100	1.745	0.00266
			30.1	4,210	140	5.10	1,400	5,440	1.760	0.00230
			22.4	2,650	163	4.00	960	2,390	1.780	0.00193
			8.66	1,300	150	2.30	425	687	1.830	0.001355
			1.905	200	105	0.42	28	18.5	2.140	0.000218
			0.715	50	70	0.06	4	0.716	2.750	0.0000153

Tables II and III and Figs. 6, 7, 8, 9, 10 and 11 give the data on uninsulated iron powder cores, both annealed and unannealed, for various pressures.

Tables IV, V, VI give data on cores of grades A, B and C. The magnetization curves for these cores are plotted in Fig. 12.

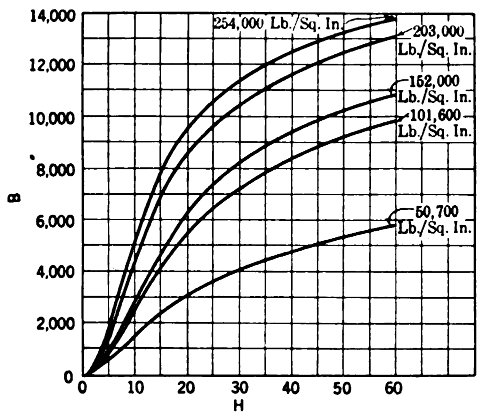

FIG. 6—MAGNETIZATION CURVES FOR ANNEALED UNINSULATED IRON POWDER COMPRESSED WITH DIFFERENT PRESSURES

DATA DERIVED FROM MEASUREMENTS OF INDUCTANCE AND EFFECTIVE RESISTANCE

Certain data as to magnetic constants are deducible from the values of inductance and effective resistance of coils especially wound on cores of the various materials. Measurements of inductance and effective resistance were made with an inductance bridge. Measurements were made for frequencies, within the audible range, of values 500, 800, 1200, 1600 and 2000 cycles per second. In all these bridge measurements the flux density of the cores was low. The measuring current was obtained from a vacuum tube oscillator which gave a sinusoidal wave. The test coils were so constructed that for the highest frequency of measuring current the energy losses in the copper winding caused by eddy currents, and also the dielectric losses

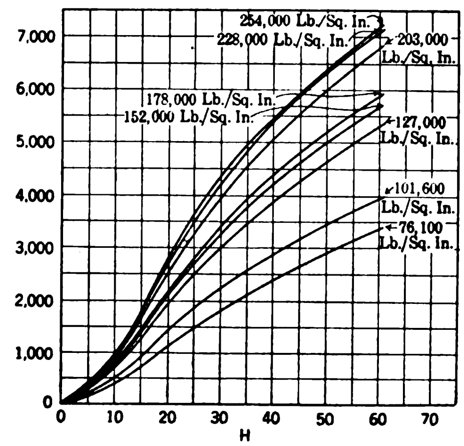

FIG. 7—MAGNETIZATION CURVES FOR UNANNEALED UNINSULATED IRON POWDER COMPRESSED WITH DIFFERENT PRESSURES

TABLE III
PROPERTIES OF UNANNEALED UNINSULATED IRON POWDER CORES

Pressure lb. per sq. in.	Sp. gr.	Sp. Res. ohm-cm.	H	B	μ	Coercive force	Remanence	W_h Ergs per cm^3 per cycle	x	η
254,000	6.7	0.0013	61.0	7,200	118	10.60	2,760	18,310	1.590	0.01365
			30.1	4,360	145	8.45	1,750	8,130	1.785	0.00259
			21.65	3,050	141	6.40	1,090	4,110	1.900	0.00100
			10.05	1,000	99.5	1.90	195	414	2.225	0.0000869
			3.03	200	66	0.16	11	8.25	2.430	0.0000247
			1.00	57	57	0.025	1.8	0.458	2.640	0.00000912
228,000	6.65	0.0016	60.1	7,100	118	11.0	2,900	19,590	1.555	0.01995
			30.3	4,300	142	8.5	1,790	8,260	1.775	0.00299
			20.3	2,720	134	6.0	1,000	3,610	1.940	0.000772
			9.8	950	97	1.9	185	389	2.200	0.000108
			3.28	210	64	0.26	18	11.3	2.455	0.00002255
			1.065	57	53.5	0.02	1.2	0.325	2.885	0.00000277
203,000	6.55	0.0019	60.7	6,800	112	11.2	2,675	18,230	1.650	0.00838
			31.0	4,100	132	8.2	1,600	7,350	1.785	0.00273
			20.7	2,650	128	6.0	950	3,385	1.950	0.000569
			10.2	935	92	1.85	175	368	2.295	0.0001432
			3.38	203	60	0.20	13	7.94	2.550	0.00001208
			1.13	59	52	0.04	1.8	0.402	2.675	0.00000662
178,000	6.4	0.0024	60.5	5,870	97	12.0	2,400	17,390	1.700	0.00686
			30.5	3,450	113	8.8	1,460	6,810	1.860	0.001803
			19.9	2,170	109	6.0	760	2,745	2.015	0.000527
			9.76	790	81	1.8	158	318	2.200	0.0001327
			3.10	170	55	0.26	14	9.55	2.430	0.0000362
			1.01	48	47	0.02	1.0	0.276	2.875	0.00000406
152,000	6.3	0.0030	58.4	5,200	89	10.6	2 050	12,600	1.615	0.01245
			30.1	3,280	109	7.9	1 260	5,870	1.800	0.00271
			20.5	2,150	105	5.4	700	2,380	1.975	0.000681
			10.12	810	80	1.9	159	334	2.215	0.000119
			3.14	163	52	0.18	10	6.69	2.585	0.00001275
			1.03	46	45	0.02	1.0	0.239	2.755	0.00000628
127,000	6.1	0.0047	62.8	5 460	87	13.5	2,150	15,710	1.700	0.00697
			28.2	2 850	101	7.9	1,100	4,870	1.980	0.000681
			18.8	1,800	96	5.0	550	1,815	2.180	0.0001435
			9.32	625	67	1.05	85	124	2.360	0.0000390
			3.11	140	45	0.15	7.5	5.73	2.535	0.00001495
			1.13	44	39	0.02	0.9	0.182	2.680	0.00000780
101,600	5.9	0.0060	61.7	3,950	64	11.4	1,375	9,980	1.620	0.01472
			31.2	2 275	73	7.3	780	3,535	1.835	0.002675
			19.1	1,425	74.5	4.8	450	1,551	2.045	0.000551
			10.0	515	51.5	1.6	75	161	2.350	0.0000673
			3.02	109	36	0.13	4.0	3.8	2.675	0.0000137
			1.00	33	33	0.02	0.9	0.105	2.990	0.000003015
76,100	5.6	0.0155	60.2	3,375	56	11.0	1,140	8,450	1.650	0.01255
			30.45	1,825	60	7.0	560	2,680	1.895	0.00183
			20.2	1,130	56	4.6	285	1,074	2.070	0.000507
			9.77	430	44	1.4	60	132.5	2.235	0.000172
			3.06	95	31	0.16	5.2	3.28	2.635	0.0000202
			0.994	28.3	28.5	0.015	0.6	0.084	3.075	0.00000287

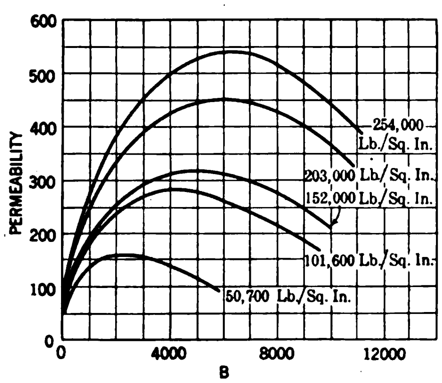

FIG. 8—PERMEABILITY CURVES FOR ANNEALED UNINSULATED IRON POWDER COMPRESSED WITH DIFFERENT PRESSURES

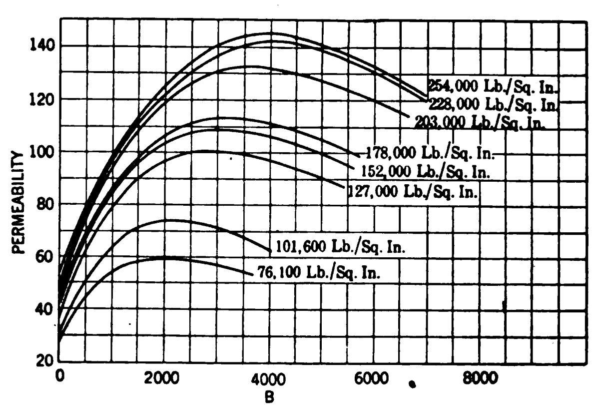

FIG. 9—PERMEABILITY CURVES FOR UNANNEALED UNINSULATED IRON POWDER COMPRESSED WITH DIFFERENT PRESSURES

were very small compared to the iron losses. These losses, were therefore, negligible and did not enter into the computation of hysteresis and eddy-current losses in the cores themselves.

From measurements of the effective resistance and inductance of the test coils there was derived the permeability of the core-material, and also the components, due to eddy currents and hysteresis respectively, of the iron losses in the core. The equations whereby these calculations were made are given below. Preceding them there is a statement of the symbols which are employed in the equations.

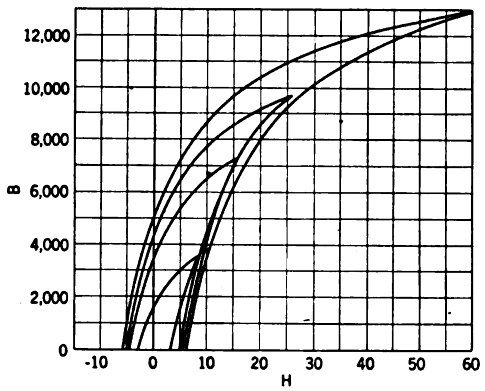

Fig. 10—Hysteresis Characteristics for Annealed Uninsulated Iron Powder Cores Compressed With a Pressure of 203,000 Lb. Per Sq. In.

The permeability of the core material was computed by equation (3). The effective resistance corresponding to the iron losses was separated into its components by equation (7), which is derived from Steinmetz's equation (1). Instead of expressing the power loss in the iron per cubic centimeter, it is more satisfactory for purposes of coil design to express the effective resistance per henry of inductance.

The transformation of the usual Steinmetz equation to the form which we have found convenient is indicated by equations (1) to (8) inclusive and the accompanying text.

L = inductance in henrys
I = current in amperes (r. m. s.)
W = power expended in ergs in the core
H = magnetizing force in gauss
B = flux density in gauss
μ = permeability

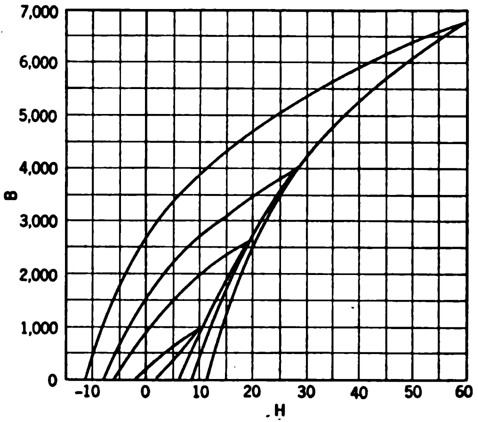

Fig. 11—Hysteresis Characteristics for Unannealed Insulated Iron Powder Cores Compressed With a Pressure of 203,000 Lb. Per Sq. In.

N = total number of turns of winding on the core
A = cross-section of core in cm².
v = volume of core in cm³.
l = mean length of the magnetic circuit in cm.
R_t = effective resistance in ohms caused by the iron losses. This is equal to the measured resistance at a designated frequency minus the direct-current resistance.
R_h = effective resistance caused by hysteresis loss
R_e = effective resistance caused by eddy current loss
x = hysteresis exponent

TABLE IV

PROPERTIES OF GRADE A IRON POWDER CORES

Sp. Res. ohm—cm.	H max.	B max.	μ	Coercive force	Remanence	W_h Ergs per cm³ per cycle	x	η	Method of test
0.6	59.9	8,260	138.0	7.25	1,725	15,550	1.64	0.00638	Ballistic galvanometer
	29.9	4,680	156.5	5.55	1,187	6,165	1.74	0.00283	"
	20.0	3,100	155.0	4.13	760	2,860	1.81	0.001595	"
	10.0	1,210	121.0	1.96	258	531	1.91	0.000750	"
	3.0	232	77.4	0.35	26.6	18.0	2.13	0.0001035	"
	1.00	61.9	61.9	0.04	3.1	0.72	2.59	0.0000184	"
	0.60	35.5	59.1	0.002	1.5	0.190	2.70	0.00001175	"
	0.155	8.78	56.5	0.002	0.1	0.00386	2.785	0.00000911	"
	0.146	8	54.8			0.00294	2.775	0.00000912	Inductance bridge
	0.128	7	54.8			0.00203	2.765	0.00000931	"
	0.1095	6	54.8			0.00132	2.750	0.00000956	"
	0.0913	5	54.8			0.000803	2.735	0.00000983	"
	0.0730	4	54.8			0.000436	2.685	0.00001055	"
	0.0547	3	54.8			0.000204	2.630	0.00001132	"
	0.0365	2	54.8			0.0000710	2.554	0.00001208	"

TABLE V

PROPERTIES OF GRADE B IRON POWDER ORES

Sp. Res. ohm—cm.	H max.	B max.	μ	Coercive force	Remanence	W_h Ergs per cm³ per cycle	x	η	Method of test
0.2	60.0	3,440	57.3	8.60	645	6,023	1.66	0.00875	Ballistic galvanometer
	30.0	1,655	55.2	5.05	312	1,787	2.02	0.000550	"
	20.0	1,000	50.0	2.60	134	561	2.22	0.0001303	"
	10.0	434	43.4	0.85	38.5	84.7	2.50	0.0000216	"
	3.0	103	34.4	0.09	3.2	2.0	2.75	0.00000515	"
	1.0	33.5	33.5	0.01	0.4	0.0852	2.75	0.00000515	"
	0.331	10	30.2			0.00290	2.750	0.00000515	Inductance bridge
	0.298	9	30.2			0.00217	2.750	0.00000515	"
	0.265	8	30.2			0.001568	2.750	0.00000515	"
	0.232	7	30.2			0.001087	2.750	0.00000515	"
	0.199	6	30.2			0.000711	2.750	0.00000515	"
	0.166	5	30.2			0.000433	2.707	0.00000555	"
	0.1325	4	30.2			0.000238	2.675	0.00000584	"
	0.0994	3	30.2			0.0001107	2.623	0.00000620	"
	0.0662	2	30.2			0.0000391	2.509	0.00000688	"
	0.0331	1	30.2			0.00000711	2.405	0.00000711	"

TABLE VI

PROPERTIES OF GRADE C IRON POWDER CORES

Sp. Res. ohm—cm.	H max.	B max.	μ	Coercive force	Remanence	W_h Ergs per cm³ per cycle	x	η	Method of test
10	60.4	2,900	48.0	9.75	690	6,000	1.84	0.00257	Ballistic galvanometer
	30.2	1,290	42.8	4.70	200	1,260	2.18	0.0002115	"
	20.1	795	39.6	2.50	96	417	2.31	0.0000804	"
	9.96	335	33.6	0.68	22	52.6	2.54	0.00001905	"
	2.99	86.8	29.0	0.07	1.7	1.49	2.72	0.00000750	"
	1.10	30.4	27.6	0.02	0.5	0.0721	2.83	0.00000455	"
	0.380	10	26.3			0.00309	2.832	0.00000455	Inductance bridge
	0.342	9	26.3			0.00228	2.832	0.00000455	"
	0.304	8	26.3			0.00165	2.832	0.00000455	"
	0.266	7	26.3			0.001125	2.810	0.00000474	"
	0.228	6	26.3			0.000729	2.786	0.00000497	"
	0.190	5	26.3			0.000441	2.751	0.00000527	"
	0.152	4	26.3			0.000242	2.719	0.00000555	"
	0.114	3	26.3			0.0001105	2.670	0.00000589	"
	0.0762	2	26.3			0.0000383	2.553	0.00000652	"
	0.0380	1	26.3			0.0000070	2.401	0.00000699	"

η = hysteresis coefficient

γ = eddy current coefficient

f = frequency in cycles per second

$$W = \eta\, v\, f\, B^x + \gamma\, v\, f^2 B^2 \qquad (1)$$

$$W = R_t\, I^2 \times 10^7 \qquad (2)$$

$$L = \frac{4\,\pi\, N^2 A\, \mu}{l \times 10^9} \qquad (3)$$

$$H = \frac{4\pi\, N\, I\, \sqrt{2}}{l \times 10} \qquad (4)$$

$$v = l\, A \qquad (5)$$

From (1) and (2)

$$R_t\, I^2 \times 10^7 = \eta\, f\, v\, B^x + \gamma\, f^2\, v\, B^2 \qquad (6)$$

Eliminating I^2 and v from this equation by means of (3), (4) and (5), gives

$$\frac{R_t}{L} = 8\pi\, \eta\, f\, \mu\, B^{x-2} + 8\pi\, \mu\, \gamma\, f^2 \qquad (7)$$

Equation (7) gives the effective resistance caused by the energy losses in the core in ohms per henry. The first member on the right-hand side of the equation is the effective resistance caused by the hysteresis loss and the second that caused by the eddy current loss.

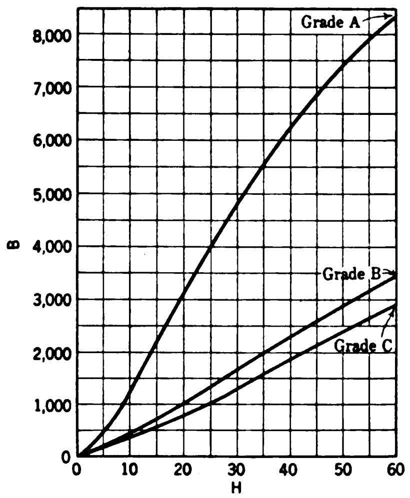

FIG. 12—MAGNETIZATION CURVES FOR GRADES A, B, AND C CORES

In order to separate the two, equation (7) is divided through by the frequency, giving

$$\frac{R_t}{L f} = 8\pi\,\eta\,\mu\,B^{x-2} + 8\pi\,\gamma\,\mu\,f \qquad (8)$$

This equation represents a straight line when plotted with $\frac{R_t}{L f}$ as one of the coordinates and the frequency

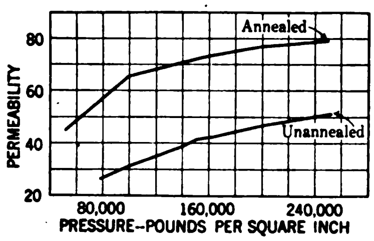

Fig. 13—Permeability at Low Magnetizing Forces for Uninsulated Iron Powder Cores Compressed With Different Pressures

as the other. The intercept of this line with the axis of $\frac{R_t}{L f}$ gives the effective resistance for a given flux density per henry per cycle, caused by the hysteresis loss. The slope of the line multiplied by the frequency gives the effective resistance, per henry per cycle, caused by the eddy current loss at that frequency.

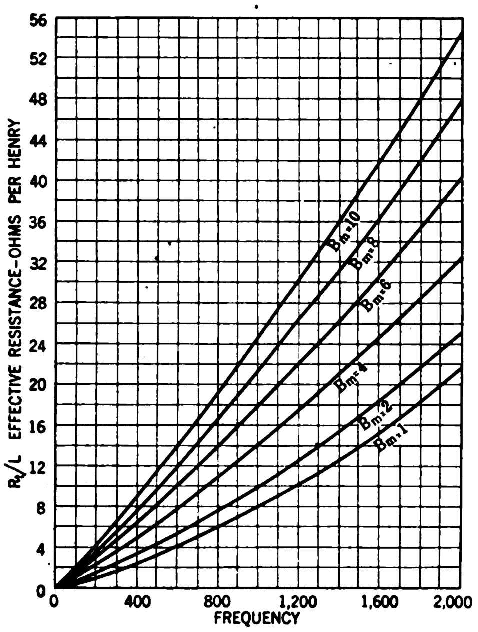

Fig. 14—Increase With Frequency in Effective Resistance Caused by the Core Losses, for Grade B Cores

The permeabilities and the magnetizing forces in the alternating-current measurements were computed by means of equations (3) and (4).

In Fig. 13 are plotted the permeabilities of the uninsulated iron-powder at low magnetizing forces and for different pressures.

In Fig. 14 $\frac{R_t}{L}$ is plotted against frequency for several densities for grade A material, and in Fig. 15 $\frac{R_t}{L f}$ is plotted against the frequency for the same flux densities.

Fig. 16 shows the variation of $\frac{R_t}{L}$ with frequency. The plot is for $B_m = 2$ gauss and permits a comparison of the three grades of material.

Fig. 17 shows, in per cent of the initial "a-c. permeability," the variation in a-c. permeability, which is

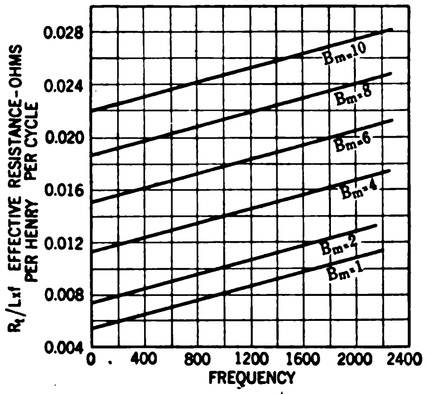

Fig. 15—Separation into its Components of Effective Resistance Caused by the Core Losses for Grade B Cores

produced by the superposition of various values of steady magnetizing force. In determining the relations of Fig. 17 the inductance bridge was used, and the a-c. permeability was calculated from the measured inductance of the test coil by the application of equation (3). In addition to the alternating current which was used for the bridge measurements there was superposed upon the windings of the test coil a direct current. The magnetizing forces corresponding to various values of the superposed d-c. are shown by the abscissas of Fig. 17. The figure illustrates the magnetic stability of the core material—a characteristic which will be discussed more fully later. It may be noted, however, that stability to superposed d-c. magnetizing forces is important in coils designed for telephonic purposes, for example, in loading coils which are to be used on composited circuits, where the inductance to the voice frequencies must not be greatly altered by the superposed telegraph currents.

Tables IV, V and VI, to which reference has already been made, give the results of computation based upon bridge measurements in addition to those derived from the ballistic measurements. Bridge measurements permit accurate determinations of the magnetic constants for low values of H. The higher values

were computed from ballistic measurements as mentioned above. The tables give hysteresis coefficients and hysteresis exponents and also energy losses per cm.[3] per cycle. The energy loss has been expressed per cm.[3] per cycle in the case of the bridge measurements to facilitate comparison with the corresponding values derived from ballistic measurements.

Discussion of Magnetic and Electrical Properties of Powdered Iron Cores

The data collected in the tables and curves give a fairly good idea of what can be done with compressed iron-powder for magnetic purposes.

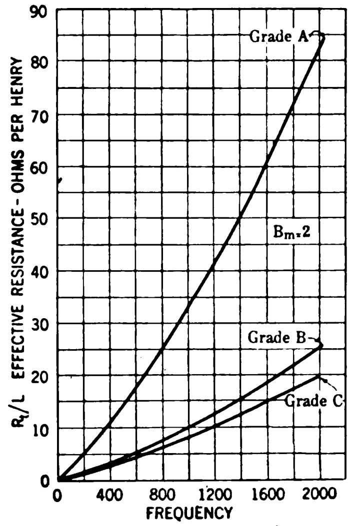

Fig. 16—Increase With Frequency in Effective Resistance Caused by Core Losses for Grades A, B, and C, With Constant B_m

When annealed, uninsulated, powder is compressed to 254,000 pounds per square inch, the specific gravity of the mass is 7.4 as compared to 7.6 for solid cast iron and 7.85 for solid wrought iron. The specific gravity of the unannealed powder at the same pressure is 6.7.

The greatest change in specific gravity occurs below 100,000 pounds pressure per square inch. (*cf.* Fig. 4). With this pressure the annealed uninsulated iron has a specific gravity of 7. For a pressure two and one-half times as large it is increased only to 7.4. Although the additional pressure increases the specific gravity very little, the maximum permeability for the same difference in pressures is more than doubled as is shown by Fig. 8. The additional pressure is, therefore, very effective in closing up the air gaps in the magnetic circuit. It appears also from Table I that high pressure is effective in producing an intermeshing of distorted iron grains which holds the compressed mass together and results in a mechanically strong structure. The microphotograph of Fig. 1 illustrates this intermeshing, as well as the thinness of the gaps between adjacent grains.

The measurements of specific resistance for cores pressed from uninsulated powder show the same characteristic variations as the specific gravity (Fig. 4). The specific resistance (Fig. 5) changes very rapidly with the pressure, for pressures below 100,000 pounds per square inch, but for higher pressures the change is more gradual. It is interesting to note that even when the specific gravity is 7. 4 the specific resistance of the compressed, uninsulated, powder is 50 to 60 times that of the solid iron.

The magnetic properties of compressed iron-powder are in general similar to those of solid iron rings. in which air gaps have been cut. The magnetization curves of Figs. 6 and 7 are sheared to the right as the value of the air gap is increased. This is due to the increase in the reluctance of the magnetic path. The magnetization curve for the highest pressure (Fig. 6) is very similar to one given by Ewing [16] for a wrought-iron bar cut into eight pieces.

There is quite marked difference between the permeabilities of the insulated and uninsulated powder. If we compare the uninsulated powder at a pressure of 150,000 pounds per square inch and a specific gravity of 7.1, with the grade A material, the specific gravity of which is the same, we find that the maximum permeability, and the retentivity of the former is more than double that of the latter. The permeability at low magnetizing forces shows a similar although

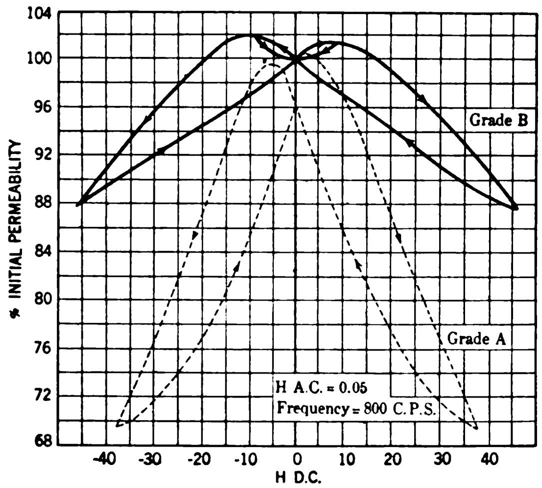

Fig. 17—The Effect of Superposed D-C. Fields on the A-C. Permeabilities of Grades A and B Cores

smaller difference. This difference is presumably caused by the way the air gaps are distributed in the two types of material. In the grade A cores each grain is insulated with a thin film which remains substantially intact while the grains are being distorted under the high pressure. In the uninsulated material it is probable that in certain parts of the mass the grains are pressed together until the air spaces between adjoining grains disappear but in other parts the air spaces are fairly large; hence the structure is that of a honeycombed mass.

16. J. A. Ewing. "Magnetic Induction in Iron and other Metals." 3rd Edition, 1900, page 292.

The maximum permeability recorded for compressed iron powder is 545. This is as high a permeability as can be obtained with many grades of solid iron as is evident from Table VII. In this table are given the maximum permeability, and the permeability for $H = 0$, for several kinds of iron and steel as tested by Gumlich and Rogowski[17], and also for several grades of compressed iron-powder as tested by the writers. For grades B and C the tabulated values of maximum permeability are those obtained with the highest magnetizing forces at which the coils were tested. At the magnetizing force of $H = 60$ the permeabilities were still slowly increasing.

TABLE VII.

Kind of Material	Permeability Maximum	$H = 0$
Electrolytic iron, wrought bar	7,800	250
Poor grade of cast steel, annealed	710	131.5
Poor grade of cast steel, hardened	170	58
Cast iron, annealed	620	175
Cast iron, unannealed	240	69.4
Iron powder, annealed, uninsulated, compressed with 254,000 pounds pressure	540	80
Iron powder, unannealed, uninsulated, compressed with 254,000 pounds pressure	156	52
Grade A iron-powder cores	156.5	54.8
" B " " "	57.2	30.2
" C " " "	48	26.3

The permeabilities of grades B and C are practically constant for flux densities below $B = 100$. For grade A this is true below $B = 50$. For flux densities below $B = 10$ there is no change in permeability that can be detected by accurate bridge measurements. This constancy is one of the important properties which makes our core-material useful for magnetic purposes.

The change in a-c. permeability when the cores are subjected to high d-c. magnetizing forces (*cf.* Fig. 17) is less for grade B than for grade A material. With a d-c. force of $H = 45$ the a-c. permeability of grade B is 85 per cent of the initial. When the force is removed the permeability returns to its original value. For grade A cores, with a d-c force of $H = 35$, the a-c. permeability is decreased to 70 per cent of its initial value and returns to 96 per cent when the d-c. force is removed.

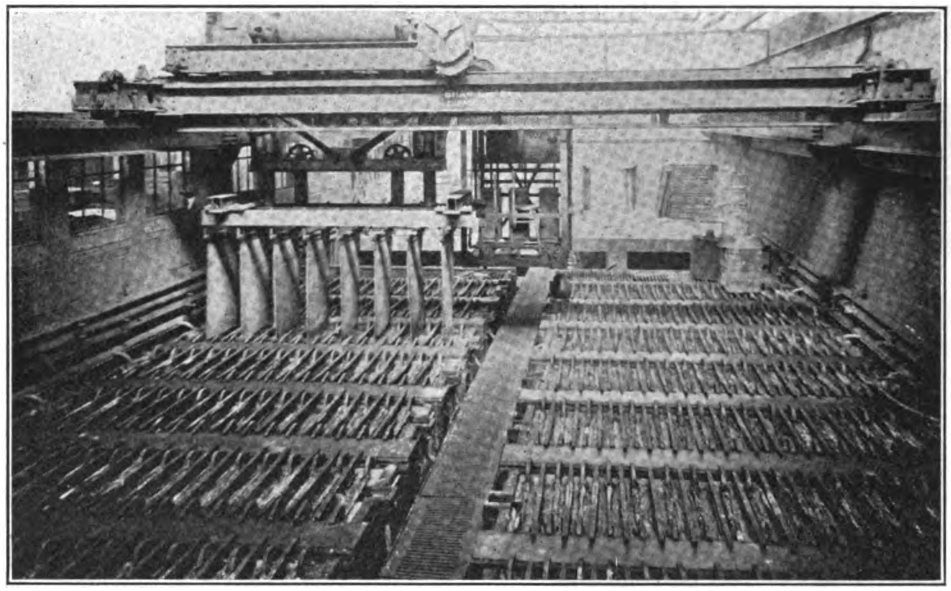

Fig. 18

For purposes of comparison it may be noted that in the case of 65-permeability iron-wire cores, which were mentioned above as standard prior to the development of the powdered iron, the stability is less than that of both grade A and grade B material. In the case of 65-permeability iron-wire cores the a-c. permeability may decrease to as little as 35 per cent of its initial value when a d-c. magnetizing force of $H = 45$ is superposed. When this superposed force is removed the permeability returns to only 62 per cent of its initial value.

From Tables IV, V and VI a comparison may be obtained of the present standardized grades of powdered iron as to the energy losses due to hysteresis. It will be noted that for flux densities below $B = 10$ the energy loss in grade A is approximately double that of grade B or grade C.

For the purpose of the design and operation of telephone equipment it is convenient to express energy losses implicitly in terms of an increase in effective resistance rather than explicitly, since the effective

17. E. T. Z. February 23, 1911.

resistance is a determing factor in the calculation of attenuations. Table VIII is added to permit a comparison of grades A, B and C in terms of increments in effective resistance. The values, there tabulated, represent differences between the resistance of test coils to currents of 800 cycles, and to direct currents, that is represent differences between effective and ohmic resistance at 800 cycles. In this table are indicated the components of the total increment in effective resistance due to hysteresis and eddy currents. The separation into components was effected by means of equations (7) and (8). The methods is illustrated by Figs. 14 and 15, but the actual values used in de-

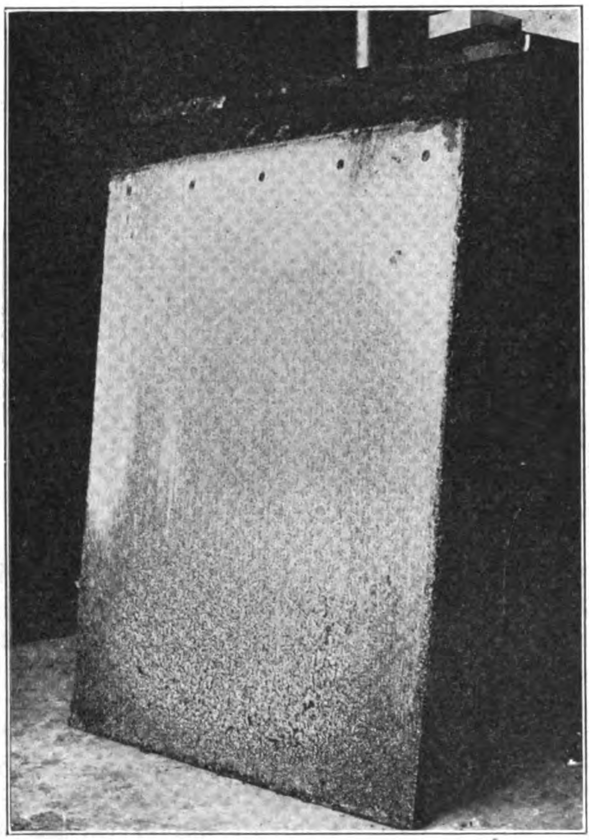

FIG. 19

termining the tabulated values were obtained from the data of Fig. 16, and correspond to the flux density of $B = 2$.

TABLE VIII.

	R_h per henry	R_e per henry	R_t per henry
Grade A cores.......	19.7	5.4	25.1
" B "	5.9	1.7	7.6
" C "	5.1	1.2	6.1

It will be noted that the effective resistance due to eddy currents is approximately 20 per cent of the total increment in effective resistance. The percentage would be less at higher flux densities as is evident from the relations of equation (7).

COMMERCIAL PRODUCTION OF POWDERED-IRON CORES

Powdered iron cores are today manufactured in large quantities by the Western Electric Company at Hawthorne, Illinois. The present equipment has a capacity of 25,000 pounds of iron powder per week.

In Fig. 18 is shown some of the equipment used in producing electrolytic iron.

It shows the electric crane lifting eight cathodes

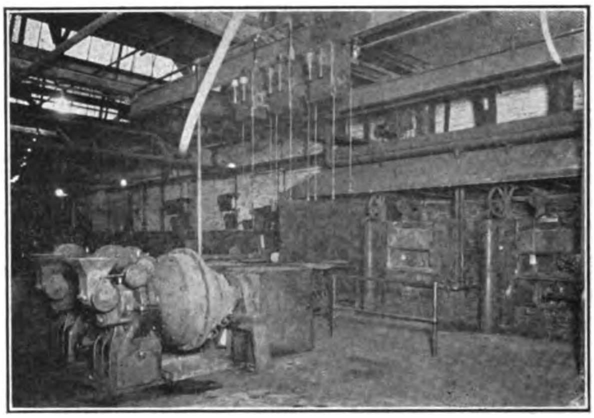

FIG. 20

with their electrolytically-deposited iron. In each tank there are sixteen cathodes and a corresponding number of anodes. In removing the cathodes only alternate ones are withdrawn at a time, partly for convenience in washing and handling, and partly so that the operating conditions in the tank will be less violently altered than if all the electrodes must be started fresh at once. The background of the figures

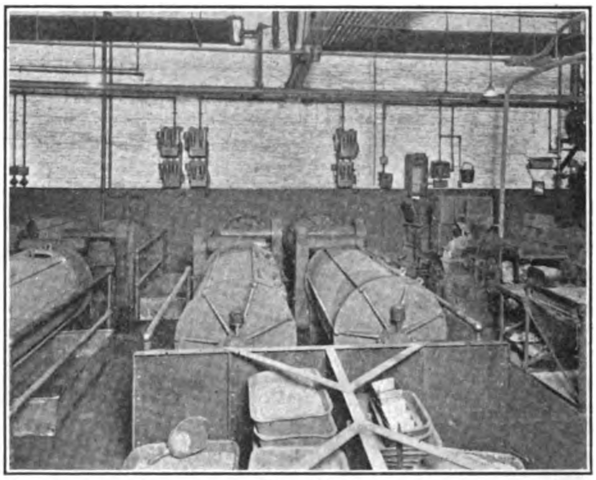

FIG. 21

shows the back of the switchboard and controllers, and also the stripping floor where the deposited iron is removed from the cathode plates.

A cathode with a full weight of electrolytic iron, ready for stripping is shown in Fig. 19.

After being stripped from the cathode the electrolytic iron is ground in a Hardinge conical-ball mill. Two of these mills are shown in Fig. 20. These mills

operate with automatic feeders and deliver their output to rotating brass sieves (80 meshes to the linear inch). In the illustration the sieves are not seen because of their rectangularly shaped iron covers. To the right of this illustration may be seen the annealing ovens.

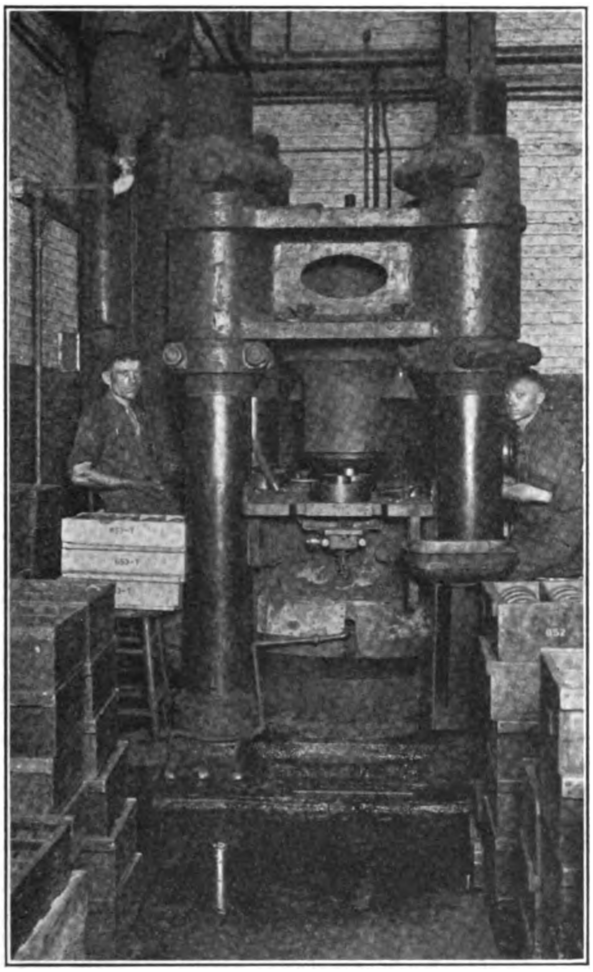

FIG. 22

The portion of the iron which is to be annealed is treated in cast-iron pots which hold about one hundred pounds each. Fig. 21 shows, at the extreme right, how the annealed iron appears as it is just being taken from the annealing pot. During the process of annealing the powdered iron is sintered to a fairly coherent mass. In order to reduce the iron to its original mesh the annealed product is passed through a rotary rock-crusher and a disk grinder. It is then sifted again by means of the jigger tables which may be seen at the right of the illustration.

The sifted powder is then rolled with flaked zinc in drums. The latter are worm-driven and four of them may be seen in the center of Fig. 21. At the extreme left of this figure may be seen four somewhat similar drums in which the powder is shellacked and dried. These are provided with steam ejectors for drawing a current of air through the shellacked mass as it dries and is slowly tumbled in the drum. For compressing the finished powder into cores there is used a short-stroke quick-acting hydraulic press which is shown in Fig. 22. This press is operated to produce a pressure of about 200,000 pounds per square inch of surface area of the finished ring. At times this press has been operated to give as high as 300,000 pounds per square inch. Severe requirements have, therefore, been imposed upon the design and construction of the steel die in which the material is compressed. The dies at present in use have been especially designed and treated and their perfection is such that several thousand rings may be pressed from a single die before it must be discarded because of wear, cracks or distortion.

The plant which has just been described has been in operation for about five years and has produced an enormous number of cores which are today widely distributed over the United States in the telephone plant of the Bell System.

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A combination radio and wireless telephone station will shortly be in operation in the City of Chihuahua, Mexico, according to Consul J. B. Stewart. The station will have a range of 6000 miles, thus putting Chihuahua in direct communication with all parts of the United States, Europe and other countries. Stations will probably be installed at Ojinaga and Ciudad Juarez and, later on, at Madera, Chihuahua.—*Commerce Reports*.

JOURNAL OF THE American Institute of Electrical Engineers

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

THE SALT LAKE CITY CONVENTION

This issue of the JOURNAL goes to press just at the time the Annual and Pacific Coast Convention is about to convene at Salt Lake City. The Convention Committee, with its numerous sub-committees, has made elaborate preparations for the entertainment of members and guests in attendance, and the excellent technical program which has been provided, combined with the natural scenic attractions of the Convention city and its environs, will afford an instructive and enjoyable occasion for all present. A full account of the meeting will appear in the August JOURNAL.

ANNUAL REPORT OF THE BOARD OF DIRECTORS

FOR THE YEAR ENDING APRIL 30, 1921

The annual report of the Board of Directors of the A. I. E. E. was presented at the annual business meeting of the Institute held in New York on Friday evening, May 20, 1921.

This report consists of a brief summary of the principal activities of the Institute during the year, including abstracts of various reports submitted by officers and committees, covering their respective branches of work. Inasmuch as most of the matters of importance referred to in the report have been, or will be, covered in much more detailed form in the JOURNAL the report will not be published in full herein, but any member of the Institute may obtain a pamphlet copy upon application to the Secretary of the Institute.

The Board of Directors held nine regular meetings during the year; four of these were held in New York, one at White Sulphur Springs, W. Va., one at Philadelphia, one at Chicago, one at Akron and one at Pittsburgh.

During the year President Berresford attended many Institute and Section meetings including the Annual and Midwinter Conventions and meetings in New York, Philadelphia, Chicago, Akron, Pittsburgh, Cleveland, Detroit-Ann Arbor, Indianapolis-Lafayette, Milwaukee, St. Louis and Schenectady

The Institute year just ended has more than fulfilled all predictions of continued growth, exceeding all previous years in committee activities, meeting attendance, and membership increase. The widespread desire to participate more actively in A. I. E. E. affairs is evidenced in the addition of six new Sections. The Branches have likewise shown a similar growth. The applications for membership received during the year were 2442; the net increase in membership amounting to 1870 or 71% over the preceding banner year. The following tabulation indicates the present membership, and the additions and deductions during the year:

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30,1920.	6	498	1615	9226	11345
Additions:					
Transferred.....	....	45	225	....	....
New Members Qualified......	....	5	124	2218	....
Reinstated......	....	3	6	78	....
Deductions:					
Died..........	....	3	6	46	....
Resigned........	....	4	12	138	....
Transferred.....	....	....	35	235	....
Dropped........	....	3	14	338	....
Membership, April 30,1920.........	6	541	1903	10765	13215

Net increase in membership during the year.......................1870.

The six Sections organized were at Akron, Ohio; Cincinnati, Ohio; Syracuse, N. Y.; Omaha, Neb.; Lehigh Valley with headquarters at Bethlehem, Pa.; and Connecticut with headquarters at New Haven. The following figures indicate the activities of the local organizations:

	For Fiscal Year Ending						
	May 1 1915	May 1 1916	May 1 1917	May 1 1918	May 1 1919	May 1 1920	May 1 1921
SECTIONS							
Number of Sections..	31	32	32	34	34	36	42
Number of Section meetings held......	246	251	265	245	217	262	303
Total Attendance....	23,507	28,553	31,299	34,614	25,837	30,741	37,823
BRANCHES							
Number of Branches.	52	54	59	59	61	62	65
Number of Branch meetings held......	328	360	368	268	156	360	443
Attendance..........	12,712	15,166	16,107	10,683	6,441	16,827	21,629

The Finance Committee's report together with the General Balance Sheet and detailed financial statements of the certified public accountants who audited the Institute books are included in the report and show that there has been a deficit of $13,892.12, which is accounted for largely by the large increase in cost of publication, one of the chief items of expense in Institute work. All activities have been carried on without curtailment and without increase of dues. In view of proposals now being considered by the Board of Directors and from reductions already evident, it is expected that the expenses for the coming year will be within the income of the Institute.

AMERICAN ENGINEERING COUNCIL

MEETING OF THE EXECUTIVE BOARD

The fourth meeting of the Executive Board of American Engineering Council was held in St. Louis on June 3, 1921. This was the first anniversary of the Organizing Conference which met in Washington last year. The meeting was well attended and full of interest, many matters of importance being discussed. One of the pleasant features was the cordial hospitality extended by the engineers of St. Louis, who entertained with an automobile drive and dinner. As a result of invitations to the leading engineering organizations in the vicinity of St. Louis a number of their representatives attended the meeting.

New Member Societies

Upon recommendation of the Committee on Membership and Representation the following organizations were admitted to charter membership in the Federated American Engineering Societies:

Iowa Engineering Society
Jamestown Engineering Society
American Society of Safety Engineers.

Considerable sentiment has developed in favor of extending the time for charter membership and as a result the Board decided to bring this matter before the next American Engineering Council meeting in January. However, all Societies which make application on or before July 1, 1921 may become charter members.

Activities of the Federation throughout the country were reported upon by the Committee on Regional Activities, showing the progress that was being made towards securing additional member organizations.

Status of F. A. E. S. and A. A. E.

During the course of the meeting some discussion took place as to the status of the Federated American Engineering Societies and the American Association of Engineers. Mr. H. O. Garman, President of the A. A. E., on being introduced announced that he had been elected President of the A. A. E. on a platform of harmony and cooperation with the F. A. E. S. It was decided that a committee of three should be appointed from each organization to determine upon the status of the two. The committee from the F. A. E. S. is composed of Messrs. Calvert Townley, Dexter S. Kimball and L. W. Wallace.

Elimination of Waste in Industry

A feature of the meeting was the presentation and consideration of the preliminary summary of the report of the Committee on Elimination of Waste in Industry. This was discussed at length. It was decided that the summary and the full report should be carefully edited in keeping with suggestions made by members of the Executive Board and that the Committee on Procedure be authorized to accept the offer of the American Society of Mechanical Engineers to arrange for the publication of the complete report in book form.

The report covered thorough investigations made by the committee since its appointment last January and disclosed vital causes of waste in industry, with suggestions for elimination. "Over 50 per cent of the responsibility for these wastes can be placed at the door of management and less than 25 per cent at the door of labor," it was stated. The investigators found that the margin of unemployment amounts to more than a million men, and that billions of dollars are tied up in idle equipment. High labor turnover was named as an index of one of the commonest wastes. A waste that runs into millions annually was reported as the loss of time and energy and money through duplication of estimates and bids in the building trade.

To aid in wiping out such wastes the report outlined a plan of nationwide cooperation between the government, the public, trade associations, the industries, labor, bankers, and engineers, indicating in what way each of these could help to solve the problem.

Announcements as to when and where copies of this report may be obtained will be made later.

A unanimous vote of thanks was tendered to the committee in appreciation of the amount of work done on the report.

Licensing of Engineers

The Committee on Licensing submitted a report containing its new recommendations on the uniform law. The committee was authorized to hold a hearing in the near future for the purpose of obtaining suggestions as to the form licensing of engineers should take.

Employment Service

A progress report of the Special Committee on the Employment Service was received. A further report from this committee will be given at the next meeting of the Executive Board.

Public Affairs Committee

The following recommendations of the Public Affairs Committee were given the approval of the Executive Board:

That no action be taken in legislation pertaining to the Federal Power Commission.

That engineering research among the colleges be fostered by Government support regardless of whether the institutions were land grant colleges or not.

That the question of legislation covering the Federal road building program be referred to the division of the National Research Council that is investigating this subject.

That if the Government wished to make an investigation of Muscle Shoals on its account by a competent engineer, Council would suggest the names of engineers to assist in making the investigation, should it be asked to do so.

That American Engineering Standards Committee plan for obtaining cooperation with the Government department be sanctioned.

Topographic Mapping Program

The Board approved support for the present bill in Congress to give increased assistance to the topographic mapping program recommended by the Board of Surveys and Maps.

Payment for Estimating

The Committee on Payment for Estimating reported that the Associated General Contractors of America and the American Institute of Architects had approved its report. The Board added its approval, and the report is to be printed in pamphlet form and given wide distribution.

Personnel Research Federation

The recommendations concerning cooperation of the Personnel Research Federation were carried over for further consideration. This federation was organized on March 15 last, to bring about interchange of research information among the numerous organizations which are engaged in personnel research. (See April, 1921, JOURNAL, p. 347.)

Representation in Building Industry

The question of representation on the National Conference Board of the Building Industry was referred to the Committee on Procedure with power in event this matter should again be brought up by the Department of Labor or the Department of Commerce.

Upon recommendation of the Committee on Procedure, Mr. J. P. Healey of Washington, D. C., was appointed alter-

nate to Rudolph P. Miller on the National Board of Jurisdictional Awards in the Building Industry.

Activities of Foreign Relations Committee

The Committee on Foreign Relations reported that it had participated in the reception and entertainment of a delegation of Italian engineers and that similar participation would be had in the entertainment of a small delegation of French engineers now visiting in this country.

A resolution to the professional engineers of Great Britain was approved by the Board expressing the admiration of the Federated American Engineering Societies for the effective work of British engineers during the war, and sympathy for the sacrifice of life, health and property. A special committee was appointed to draft a suitable resolution to the French engineers.

Resolutions to Herbert Hoover

Resolutions to Mr. Herbert Hoover which had been drafted by a special committee were approved, and it was ordered that they be engraved and forwarded to Mr. Hoover. The resolutions put on record the appreciation of the Executive Board of American Engineering Council for Mr. Hoover's judgment and vision in directing the initial policies of The Federated American Engineering Societies, and expressed the regret with which his resignation from the presidency had been accepted, with good wishes for a continuation of the distinguished success which has followed him in his past services to his profession, his country and mankind.

Next Meeting in September

The next meeting of the Executive Board will be held in September, the time and place to be announced later.

AMERICAN ENGINEERING STANDARDS COMMITTEE

A. I. E. E. STANDARDS SUBMITTED FOR APPROVAL

The American Institute of Electrical Engineers has submitted its Standards (1921 edition) to the American Engineering Standards Committee for approval as an American Standard. The Standards are submitted in accordance with the special provision in the procedure of the committee under which important standards adopted or in process prior to 1920 may be approved without going through the regular process followed in new work. The standards submitted represent the latest revision of the A. I. E. E. standardization rules, revised during 1919 and 1920. The first edition of the rules was issued in 1899.

The American Engineering Standards Committee would be very glad to learn from those interested of the extent to which they make use of these specifications and to receive any other information regarding the specifications in meeting the needs of the industry.

The Standards of the A. I. E. E. are issued in a 172-page book in flexible cloth binding. Copies may be obtained from the American Engineering Standards Committee, 29 West 39th Street, New York, price $2.00; or from the A. I. E. E., with a discount of 25 per cent to Institute members.

COPPER SPECIFICATIONS APPROVED

Standards recently approved by the American Engineering Standards Committee include four Copper Specifications submitted by the American Society for Testing Materials as "Tentative American Standard," as follows:

9-1921 Soft or Annealed Copper Wire.
10-1921 Lake Copper Wire, Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.
11-1921 Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.
12-1921 Battery Assay of Copper.

SECTIONAL COMMITTEES RECENTLY DESIGNATED

Standard of Aluminum for Conducting Purposes

In compliance with the request of the American Institute of Electrical Engineers, the American Engineering Standards Committee has designated the A. I. E. E. sponsor for the formation of a sectional committee on "Standard of Aluminum for Conducting Purposes."

Symbols for Electrical Equipment of Buildings and Ships

n conformity with the request of a conference of interested national organizations, the A. E. S. C. has designated the American Institute of Architects, the American Institute of Electrical Engineers, and the National Association of Electrical Contractors and Dealers, joint sponsors for a sectional committee on Symbols for Electrical Equipment of Buildings and Ships.

Mining Standardization

Upon recommendation of its General Correlating Committee for Mining Standardization, the A. E. S. C. has authorized the organization of sectional committees on "Safety Rules for Installing and Using Electric Equipment in Bituminous Coal Mines," "Portable Electric Mine Lamps," and "Storage Battery Locomotives for use in Gaseous Mines." The U. S. Bureau of Mines has been designated as sponsor for each of these sectional committees.

1920 ENGINEERING INDEX ISSUED

The American Society of Mechanical Engineers has just issued the 1920 volume of The Engineering Index, which has been delayed because of the printing situation. The volume retains the alphabetical index found satisfactory in the 1919 volume. It contains nearly 14,000 items referring to articles in some 700 engineering and technical publications, and is a comprehensive guide to the engineering literature of 1920.

Copies of the 1920 volume may be obtained from the American Society of Mechanical Engineers, 29 West 39th Street, New York City. The price is $6.00.

ADDRESSES WANTED

A list of members whose mail has been returned by the postal authorities, is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Wm. J. Cochran, 248 Wellesly St., Toronto, Ont., Can.
2.—R. Coelho, 210 West 95th St., New York, N. Y.
3.—L. de La Pena, 13 Olozaga, Madrid, Spain.
4.—Frederick G. Doane, Box 168, Groton, Conn.
5.—W. F. Gantvoort, Kedongsarie 84, Soerabaia, Java, Dutch East Indies.
6.—Louis E. Given, 72 West Adams St., Room 634, Chicago, Ill.
7.—I. Goldberg, 35 Euclid Ave., Toronto, Ont., Can.
8.—Jonathan M. Keller, Box 121, Sparrows Point, Md.
9.—John Neilson, 344 West 72nd St., New York, N. Y.
10.—Basil B. Pilcher, 691 East 230th St., New York, N. Y.
11.—M. J. Pouillon, 95 Straps St., Gent, Belgium.
12.—Albert G. Scholer, Dundee Lake, N. J.
13.—Martin Tracy, Tunnel Camp, Brittiania Mines, Howe Sound, B. C., Can.
14.—Harry Wilson, J. G. White Engg. Corp., Marcus Hook, Pa.

JOHN FRITZ MEDAL AWARDED TO EUGENE SCHNEIDER

The John Fritz Medal Board of Award has awarded its gold medal and diploma to Charles Prosper Eugene Schneider, the distinguished French engineer, scientist, and man of affairs. This high honor bestowed by American engineers was awarded to Mr. Schneider, "for achievement in metallurgy of iron and steel; for development of ordnance, especially the 75 mm. gun, and for notable patriotic contribution to the winning of the war."

Mr. Schneider heads the great Creusot engineering and steel works and shipbuilding plants of France, which with their subsidiaries have 100,000 employees. No industrial establishment in the whole world made a greater contribution to the defense of liberty or showed more wonderful resourcefulness under the stress of war from 1914 to 1918.

Mr. Schneider has led not only in the technical and commercial development of the great and varied steel and other engineering industries of France, but he has also given effective attention to the well-being of his men and their families. His schools for workmen, foremen and engineers are among the best in the world. As early as 1877 his company introduced a pension system, antedating similar action by the French Government. A very large proportion of his men own their own houses and gardens. He has successfully done much to raise the standards, broaden the outlook and bind the loyalty of his men.

Born October 29, 1868, at Le Creusot, he has devoted his life to the development of the great industries which his forefathers founded. Upon the death of his father in 1898, he became the head of the company, when only thirty years of age. He was a member of the Chamber of Deputies, of the French Parliament from 1898 to 1910. He has received many honors in his own and other countries for his noteworthy achievements. While in the United States in November 1919, he was presented with the gold medal of the Mining and Metallurgical Society of America. His noble and lovable personality has won many friends.

The medal and diploma will be presented to Mr. Schneider in France by a party of distinguished American engineers which sailed for Europe in June. This party is led by Mr. Ambrose Swasey, Chairman of the Board of Award, and includes several other officers and past officers of the national societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers of the United States. It was scheduled to present the 1921 award to Sir Robert A. Hadfield in England on June 29th, as announced in a previous issue of the JOURNAL. The award to Mr. Schneider is for 1922, anticipated so that the same deputation might continue to France to make the presentation, which will take place early in July.

PERSONAL MENTION

G. M. EVANS, consulting engineer of New York City, is at present with Easton & Evans, Keeseville, N. Y.

FORREST E. BROOKS has left the New York Telephone Company to become chief engineer for the Cole Process Company of America, Inc., New York City.

THEOPHILUS JOHNSON, JR., has become general manager of the Wireless Specialty Apparatus Company, Boston. He was formerly with the General Electric Company.

ALEX DOW, president and general manager of the Detroit Edison Company, has been appointed a member of the board of directors of the Detroit United Railway.

W. J. CRAWFORD is now with the Electric Storage Battery Company, New York City. Until recently he was sales engineer for the Cutler-Hammer Mfg. Company, New York.

WM. S. GOULD, who was with John A. Stevens, at Lowell, Mass. and Cleveland, Ohio, is now in the Engineering Department of The Cleveland Discount Company, Cleveland.

J. B. ADAMS has become sales manager for Schweitzer & Conrad, Inc., Chicago. Mr. Adams left the Standard Insulation Company, Rutherford, N. J., to take up his new work.

C. A. MALINOWSKI has left his position as electrical foreman of the Magna Plant of the Utah Copper Company, and is now with the Westinghouse Electric Company, Salt Lake City, Utah.

COLIN K. CARR, formerly with the Firestone Tire & Rubber Company, Akron, Ohio, has entered the employ of the Commonwealth Edison Company, Chicago. He will be in the Operating Department.

FRANK M. KNIGHT, formerly electrical draftsman with ALBERT C. WOOD, consulting engineer of Philadelphia, is now in the Shop Engineers Office of the Lima Locomotive Works, Inc., Lima, Ohio.

CHARLES S. HAMNER, of the firm of Hamner & Quick, general engineers and inspectors, announces that the group of engineers of which his firm is a part has greatly enlarged its quarters at 35 Nassau Street, New York City.

JOHN W. BOWDLE, of the Pacific Telephone & Telegraph Company, has been transferred from San Diego, Cal., to Los Angeles, as switchboard engineer. His work in San Diego was that of wire chief.

H. H. HORNING has left the Cutler-Hammer Mfg. Company of Milwaukee, and is now located with the Power Engineering Department of The Philadelphia and Reading Coal and Iron Company, Pottsville, Pa.

P. D. WAGONER has located with the Elliot-Fisher Company, in the Canadian Pacific Building, New York City. Mr. Wagoner was until recently an executive with the General Motors Corporation, New York.

VINCENT J. WOODCOCK is now connected with the Crowe-Woodcock Company, Worcester, Mass. He was formerly manager of the Electric Fixture & Appliance Departments of the Economy Electric Company, Worcester.

M. A. MAXWELL has recently become vice-president and general manager of the Beckley Pocahontas Coal Company, Huntington, W. Va. His former position was general manager of the Logan County Light & Power Company, Logan, W. Va.

CHARLES G. DU BOIS, president of the Western Electric Company, has lately returned from a six weeks' visit to Europe, where he made a study of European economic conditions. He traveled in France, Switzerland, Austria, Hungary, Germany, Belgium, and England.

H. E. KAIGHN, consulting engineer, has severed his active connection with the Wilmington Sugar Refining Company, and has resumed his general practise with offices at 3143-45 Du Pont Building, Wilmington, Del. He is still retained by the company as a consulting engineer.

W. W. HEADINGS, who has been with the Carballoy Products Company, Bellevue, Ohio, as chief engineer, has secured a fellowship at the Carnegie Institute of Technology, where he is an instructor in the Physics Department, and is also doing research work on developing carbons for electrical purposes.

ALLAN V. GARRATT has opened an office in Boston, at 176 Federal Street, for consultation and advisory work in hydraulic engineering. Mr. Garratt was formerly chief engineer of the Lombard Governor Company, and more recently consulting hydraulic engineer to Lockwood, Greene & Company, Engineers.

AARON L. NELSON, of Deer Lodge, Montana, has sailed for South America. His address will be: General Electric Company, Caixa Postal 547, Sao Paulo, Brazil, S. A. Mr. Nelson has been with the General Electric Company since 1909, and represented it in the electrification of the Chicago, Milwaukee and St. Paul Railway.

A. E. KENNELLY, professor of electrical engineering at Harvard University and the Massachusetts Institute of Technology, sailed in June to take up his work as exchange professor in French Universities. (See June JOURNAL, page 506.) Dr. Kennelly will spend a year in France, on leave of absence from his positions here.

LOUIS COHEN, consulting engineer, Signal Corps, sailed for France on June 7th to attend the meetings of the Provisional Technical Committee of the International Conference on Electrical Communication. Dr. Cohen, Major General George O. Squier, and Major Joseph O. Mauborgne will represent the War Department at this conference.

CHARLES H. DRAKE, formerly assistant division traffic engineer with the Western Union Telegraph Company, Lake Division, Chicago, has been appointed supervisor of automatics for the Canadian National Telegraphs, with headquarters at Toronto, Ontario. Mr. Drake has been identified with the development and operation of automatic printing telegraphs since 1913.

E. J. CONDON, JR., has become assistant general manager of the Intermountain Railway, Light & Power Company, with headquarters in Colorado Springs, Colo. Mr. Condon is also vice-president of the Condon Engineering Company of Chicago, and has held executive positions with the Indiana Utilities and other companies, his work bearing especially on central-station operation.

C. W. KOINER has been appointed city manager for Pasadena, Cal., with power of administration in all departments of the city except the library and legal. Mr. Koiner has been general manager and mechanical-electrical engineer of the city's Electric Utility for thirteen years, having had previous to that time a wide experience in the construction and management of electrical plants.

JAMES DIXON, who for the past year has been production manager of the Reliance Electric and Engineering Company of Cleveland, Ohio, has been made works manager of that company. Prior to joining the Reliance staff Mr. Dixon was employed by the Crocker Wheeler Company at Ampere, N. J., for ten years in various capacities. During the war he was enrolled as junior lieutenant in the Naval Reserve, but was not called to active service.

G. C. THORNTON has opened an office at 308 First National Bank Bldg., Huntington, W. Va., for the practise of Electrical Engineering, specializing in designing and supervising construction of steam and electric power plants for mines, and the mining and handling of coal by machinery. Mr. Thornton has had broad experience in this line of engineering, having installed some of the largest plants in the Alabama coal fields, prior to the war, during which he served as Major, Corps of Engineers.

P. G. AGNEW has returned from a short trip to Europe to attend a conference in London of the secretaries of the national standardizing bodies. (A brief account of this conference, as *The Engineer*, London, reviewed it, will be found on page 560 of this issue of the JOURNAL.) Dr. Agnew visited France, Switzerland, and Germany after the conference, to make a more detailed study of the standardization work in those countries.

PHILIP BELL WOODWORTH has been elected president of Rose Polytechnic Institute at Terre Haute, Ind. Dr. Woodworth is an engineer of wide practise as well as teaching experience, most of his engineering work being done under the firm name of Rummler, Rummler & Woodworth, attorneys and engineers. For a number of years before the war he was dean and professor of electrical engineering at Lewis Institute, Chicago. Since 1917 he has been in government service serving successively as executive secretary of the National Council of Defense, regional director for the North Central States, in charge of vocational training for enlisted men, and corps consultant of the War Plans Division of the U. S. Army, at Fort Sheridan, which position he is leaving to accept the one at Terre Haute. Rose Polytechnic Institute is an engineering college of the first rank. It was opened in 1883, and has graduated a long line of engineers, many of whom have become distinguished in their profession. Dr. Woodworth will enter upon his new duties at once.

OBITUARY

FRANK TAYLOR GASH, of the West Penn Power Company, Springdale, Pa., died on May 23, 1921 in his 34th year. Mr. Gash was born in California, and was graduated from the Polytechnic College of Engineering at Oakland, Cal. Most of his life was spent in California until he located in the east after the war, except for an interval of about two years during which he was with the Westinghouse Electric & Mfg. Company of E. Pittsburgh. He died suddenly in Tarentum, Pa., where he made his home. Mr. Gash had been an Associate of the INSTITUTE since 1912.

CHARLES NELSON VANDERHOOF of Newark, N. J., died in that city on April 19, 1921. Mr. Vanderhoof was born September 16, 1881, in Newark. He began his career at an early age on construction work with the Westinghouse Elec. & Mfg. Company. Leaving this position, he was employed for several years in the same line of work with the New York Edison Company. He entered the employ of the Public Service Electric Company of N. J. in July 1903. During eighteen years' service with this company, he held the following positions: Wireman, electrician, foreman, and division foreman in charge of electrical construction work. Mr. Vanderhoof's devotion to duty and untiring energy were exceptional. He had an excellent character and pleasing personality and consequently had a wide circle of friends. He joined the INSTITUTE in 1915. He was also a member of the National Electric Light Association, and of a number of fraternal orders.

CLARK WILSON FRANCY died on May 6, 1921, at a military hospital, Oteen, North Carolina. Lieutenant Francy's death followed an operation which it had been hoped would effect his recovery from illness contracted in the trenches during service overseas. He had been confined to military hospitals since his return to this country in April 1919. Lieutenant Francy was born in Toronto, Ohio, in 1886, and resided there

practically all of his life. He was graduated from the Case School of Applied Science in 1910 and started to work at once with railway and lighting companies in Ohio, becoming chief electrician for the Steubenville & E. Liverpool Ry. & Lt. Company. He was highly regarded by his associates as a man of sterling qualities. He had been a student member of the INSTITUTE in his college days, and became an Associate in 1916.

WILLIS H. TRENNER. Word has been received of the death of Willis H. Trenner on March 12, 1921. Mr. Trenner was chief engineer and superintendent of power of the Idaho Power Company, Boise, Idaho. His engineering career started upon his graduation from the Washington State College in 1903. He was employed in Tacoma, Wash., until 1905; next with the Portland Ry., Light & Power Company, in charge of electric design and construction of stations and substations, for two years; and from 1908 until his death he was in Idaho, first as superintendent of the Idaho-Oregon Light & Power Company, and then with the Idaho Power Company as above. Mr. Trenner was born at Goldendale, Wash., in 1879. He joined the INSTITUTE in 1911.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES MAY 1-31, 1921

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

APPLIED ELECTROCHEMISTRY AND METALLURGY.

By Charles F. Burgess, H. B. Pulsifer and B. B. Freud. Chicago, American Technical Society, 1920. 198 pp., illus., 8 x 6 in., cloth. $2.50.

A volume intended for the beginner or the reader desiring a concise summary of the most important commercial processes. The electrochemical section treats of such applications of electricity as electric furnaces, electroplating, the electrolytic refining of metals, and electrical discharges in gases. The metallurgical section reviews the customary practise in the metallurgy of iron, copper, lead, zinc and gold.

DIE BERECHNUNG ELEKTRISCHER LEITUNGSNETZE IN THEORIE UND PRAXIS.

By Josef Herzog and Clarence Feldman. Dritte auflage. Berlin, Julius Springer, 1921. 731 pp., diagrams 9 x 6 in.

The third edition of this thorough treatise on conducting networks has been thoroughly revised and enlarged, so that the treatment is both more extensive and more intensive than before. The book is a systematic theoretical and practical discussion of the subject, from the simplest conducting systems to the distribution of current and pressure in long conductors. Bibliographies are appended to the various chapters.

THE ELECTRODEPOSITION OF COPPER, AND ITS INDUSTRIAL APPLICATION.

By Claude W. Denny. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's technical primer series.) 108 pp., illus., 7 x 4 in., boards, $1.00.

The object of this small book is to touch on the principles of electrodeposition from a practical point of view, and to give special attention to the rapid strides made during the last five or six years, owing to the shortness of copper and as adjunct to existing methods of manufacture.

THE ENGINEER.

By John Hays Hammond. N. Y., Charles Scribner's Sons, 1921. (Vocational Series). 194 pp., 7 x 4 in., cloth. $1.25.

Mr. Hammond's book is intended as guide and counsellor for the youth attracted toward engineering as a profession. Its advantages and disadvantages, the qualities required for success, the best kind of education are clearly set forth, followed by chapters which explain the fields occupied by the major divisions of engineering—mechanical, civil, mining, chemical marine and military. The book is well fitted to assist in the selection of a career.

L'ETHER ET LA THEORIE DE RELATIVITE.

By Albert Einstein. Paris, Gauthier-Villars et Cie, 1921. 15 pp., 9 x 6 in., paper. 2.50 fr.

This short pamphlet is a translation of a lecture delivered at the University of Leyden on May fifth, 1920, in which the theory of action at a distance and the undulatory theory of light are discussed in relation to the existence of ether.

FUNFSTELLIGE TAFELN DER KREIS—UND HYPERBELFUNKTIONEN.

By Keiichi Hayashi. Berlin, Walter de Gruyter & Co., 1921. 182 pp., 9 x 6 in., paper. (Gift of the Author).

The values given in this table are in ten-thousandths from 0 to 0.1, in thousandths from 0.1 to 3, in hundredths from 3 to 6.3 and in tenths from 6.3 to 10. The circular and hyperbolic functions of any number are printed side by side, making it unnecessary to consult two places when using formulas containing both functions.

HILFSBUCH FUR DIE ELEKTROTECHNIK.

By Karl Strecker. Neunte auflage. Berlin, Julius Springer 1921. 662 pp., illus., 8 x 5 in., cloth. 70 M.

The ninth edition of this handbook, the first in eight years, follows the lines of the earlier editions, but has been thoroughly revised and largely rewritten. Considerations of cost have caused the omission of those sections devoted to weak-current engineering, primary cells, electric igniting and similar topics, so that the book is now concerned only with heavy-current work. Like earlier editions, this contains numerous useful references to important literature on various subjects.

AN INTRODUCTION TO TECHNICAL ELECTRICITY.

By S. G. Starling. Lond., Macmillan and Co., Ltd., 1921. (Macmillan's Life and Works Series). 181 pp., illus., 7 x 5 in., cloth. (Gift of The Macmillan Co., N. Y.) $2.00.

An elementary text-book addressed to students who require instruction in electricity of a practical kind, closely related to actual practise. Intended for use for vocational instruction in elementary and continuation schools.

Lehrgang der Schaltungsschemata Elektrischer Stark-strom-Anlagen.

By J. Teichmuller. 1. Band. Schaltungsschemata fur Gleichstromanlagen. 2. Auflage. Munchen und Berlin, R. Oldenbourg, 1921. 131 pp., diagrams, 12 x 9 in., boards. 60 M.

This work comprises diagrams of wiring and connection diagrams for direct-current generating stations of many kinds, accompanied by explanatory notes. The schemes shown include wiring for plants with and without storage batteries, voltage regulation, three-wire systems, stations for light and power, substations and measuring instruments. There are also given the wiring plans of a number of German central stations for general and special purposes.

The Microscope; Its Design, Construction and Application.

Edited by F. S. Spiers. Lond., Charles Griffin & Co., Ltd.; Phila., J. B. Lippincott Co., 1920. 260 pp., plates diagrams, 10 x 7 in., cloth. $5.00.

This volume contains the papers and addresses delivered at a meeting held in January, 1920, at the initiative of Sir Robert Hadfield, by the Faraday Society, the Royal Microscopical Society, the Optical Society and the Photomicrographic Society. One purpose of the symposium was to stimulate the study of and research in microscopical science by indicating lines of progress in the design of the instrument, showing recent improvements in the microscope and its technique, and its varied uses as an instrument of research.

The papers cover a wide field, including among other subjects the mechanical design, optics and manufacture of microscopes; their applications especially in metallography, metallurgy, engineering and metrology; their testing. An historical introduction is given and a bibliography of the chief literature.

Municipal Engineering.

By H. Percy Boulnois. Lond. and N. Y., Sir Isaac Pitman & Sons. Ltd., 1921. (Pitman's technical primer series.) 103 pp., 7 x 4 in., boards. $1.00.

This small volume is an introductory essay on the profession intended to draw attention to its present position and increasing importance, and to point out to those who think of embracing it as a vocation, the manner in which they should be equipped and the subjects they should study.

National Electrical Safety Code

Issued by the U. S. Bureau of Standards. Third edition. Wash., Govt. Printing Office, 1921. (Handbook series no. 3). 366 pp., 8 x 5 in., cloth. $.40.

About four years ago the Bureau of Standards published the completed text for this Code for examination and trial use, an early revision being contemplated. War conditions interfered with this trial, so that the publication of a new edition has been greatly delayed. The revision is now completed and the revised code is now published in this handbook for more convenient use. The discussion of the rules has been segregated under a separate cover so as to reduce the bulk of the main volume, and will appear as Bureau of Standards Handbook No. 4, now in press.

Oil Fuel.

By Edward Butler. Fourth edition. Lond., Charles Griffin & Co., Ltd., Phila., J. B. Lippincott Co., 1921. 310 pp., illus., 8 x 5 in., cloth. $3.75.

This book is intended as an exhaustively and systematically classified record of the developments and progress in the application of oil fuel for all steam raising, metallurgical and other purposes, except internal combustion engines, for which liquid fuel can be used successfully. The present edition has been thoroughly revised and much enlarged.

The Open Hearth; its Relation to the Steel Industry, Its Design and Operation.

First edition. Cleveland, O., The Wellman-Seaver-Morgan Co., 1920. 378 pp., illus., 11 x 9 in., cloth. $7.50. (Sold by U. P. C. Book Co., Inc., N. Y.)

This is a practical book on the design and construction of the open-hearth furnace, and on its use in modern steel-making. The methods of working, the gas producers, metal mixers, charging machines and other auxiliaries are described, so that the volumes form a complete, though brief account of open-hearth practise, very fully illustrated by drawings, half-tones and tables of data.

Personnel Relations in Industry.

By A. M. Simons. N. Y., The Ronald Press Co., 1921. 341 pp., 9 x 6 in., cloth. $3.00.

The first part of this work gives a survey of the situation in American industry and analyzes the elements of the employment problem. The specific stages through which the questions at issue have passed are then reviewed after which the author summarizes the best recent thought on the broad question of democracy in industry. Throughout the author has tried to call attention to the scientific laws that have emerged from recent study of the subject and to determine the reactions of human nature to the conditions presented in the various industrial problems.

Die Praktische Nutzanwendung der Prufung des Eisens Durch Atzverfahren und mit Hilfe des Mikroskopes.

By E. Preuss. Zweite auflage. Berlin, Julius Springer, 1921. 124 pp., illus., 9 x 6 in., paper. 14 M.

The present book is intended as a guide in the practical use of microscopic methods of testing the quality of iron, of sufficient scope to meet the ordinary needs of steel-works metallurgists and testing engineers. The methods of etching and polishing are given and the useful tests for determining structure, controlling heating, tempering, etc., are described.

Rayons X et Structure Cristalline.

By W. H. Bragg and W. L. Bragg. Translated from the third English edition. Paris, Gauthier-Villars et Cie, 1921. 209 pp., illus., 9 x 6 in., paper, 12 fr.

The work here presented in translation is an interesting and valuable account of the recently introduced method of investigating crystals by x-rays, a method that has not only thrown light on crystalline structure, but also on the nature of x-rays themselves. The authors describe their methods, their researches upon the diffraction of x-rays and the most notable results obtained.

Relativity, The Electron Theory and Gravitation.

By E. Cunningham. Second edition. London and N. Y., Longmans, Green and Co., 1921, 148 pp., 9 x 6 in., cloth. $3.50.

The primary purpose of this monograph was to set out as clearly and simply as possible the relation of the principle of relativity to the electron theory, in a way useful to the general reader and especially to the experimental physicist. In the present edition a second section has been added, which presents the general principle in its present form.

Small Motors, Transformers, Electromagnets.

By H. M. Stoller, F. E. Austin, E. W. Seeger. Chicago, American Technical Society, 1920. 320 pp., illus., 8 x 6 in., cloth. $3.00.

The first section of this book discusses small motors, automobile starting motors and charging generators and farm lighting outfits. The practise of the Western Electric Company in designing small motors is described, and instruction is given in rewinding small direct and alternating-current motors to change their characteristics. Typical designs are given for d-c. motors of all standard voltages, ranging from 0.01 h. p. to 0.5 h. p. in size, and for a-c. induction motors from 0.125 to 0.5 h. p. in size.

The second section, on small low-tension and high-tension transformers, treats of those which will transform from 110 to 220 volts and down to the lower voltages. The instruments described include a 10,000-volt, a 2,200-volt, a 10-volt, and a 22-volt transformer.

The concluding section includes typical designs of electromagnets for direct and alternating-current work and induction coils. Flat-plunger, cone-plunger, horseshoe and clapper electromagnets and portative magnets are considered.

La Theorie de la Relativite Restreinte et Generalisee.

By A. Einstein. Paris, Gauthier-Villars, et Cie., 1921. 120 pp., 7 x 5 in., paper. 7 fr.

This French edition of Dr. Einstein's popular presentation of the theory of relativity is based on the second German edition. A lengthy preface by Emile Borel discusses the value of the theory and the limits of its practical use.

Die Transformatoren.

By Milan Vidmar. Berlin, Julius Springer, 1921. 702 pp., illus., 10 x 6 in., paper. 110 M.

Contents:—Der Eisenkern.—Die Wicklungen.—Das Gestell des Transformators.—Die Erwarmung des Transformators.—Die Probleme des Transformatorenbaues.—Der Preis und der Wirkungsgrad.—Der Preis und die Hauptabmessungen.—Der

Kleintransformator. Der Trockentransformator. Der Öltransformator.—Der Grosstransformator mit Wasserkuhlung.—Die Parallelschaltung von Transformatoren.— Das Transformieren der Phasenzahl.—Die Messungen des Transformatorenbaues.

This extensive treatise discusses the theory and practise of transformer construction, on the basis of many years experience. Numerous examples, taken from actual installation, are included.

UNITED STATES STEEL: A CORPORATION WITH A SOUL. By Arundel Cotter. Garden City, N. Y., Doubleday, Page and Co., 1921. 312 pp., ports., plates, 8 x 6 in., cloth. $3.00.

This is an enlarged and modernized edition of "The Authentic History of the United States Steel Corporation." It gives a well-written account of the reasons for its organization, its history, activities, aims and policies, relations with its employees, together with some account of important officials, past and present.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—May 25, 1921. Paper: "Light and Shade." Author: Mr. A. L. Powell, Edison Lamp Works of the General Electric Company. The talk was illustrated with a series of lantern slides showing examples of illumination. Attendance 25.

Baltimore.—May 20, 1921, Engineers Club. Mr. J. T. Corrin, of the Pittsburgh Transformer Company, presented a paper dealing with the recent developments in the design and manufacture of transformers. A number of pictures of transformers of the different types manufactured by the Pittsburgh Transformer Company were shown. Attendance 125.

Boston.—May 24, 1921, Auditorium, Engineers Club. Business meeting and election of officers as follows: Chairman, Lewis W. Abbott; Vice-Chairman, Edward L. Moreland; Secretary, F. S. Dellenbaugh, Jr.; Treasurer, Ira M. Cushing. After all business had been disposed of a social meeting took place during which refreshments were served. Attendance 140.

Chicago.—May 26, 1921, Congress Hotel. Meeting held in conjunction with Power Section of the A. S. M. E. Subjects: "Location and Distribution of Central Station Power in the Middle West" by Mr. W. L. Abbott, Commonwealth Edison Company; and "Power Production and Use" by Mr. C. W. Place, General Electric Company. Attendance 300.

Cincinnati.—May 12, 1921, Assembly Hall, Union Gas & Electric Company. Subject: "Cost of Electric Service in View of Present Economic Trend." Speaker: Mr. P. M. Lincoln, Lincoln Electric Company. Attendance 25.

June 9, Cincinnati Country Club. Business meeting and election of officers as follows: Chairman, J. D. Lyon; Secretary-Treasurer, Leo Schirtzinger; Executive Committee, Messrs. A. M. Wilson, C. W. DeForest and Wm. S. Culver. The Chairman called on various members for short talks. Attendance 30.

Connecticut.—May 13, 1921, Lampson Lyceum, Yale University. Paper: "Preservation and Utilization of Niagara Falls." Author: Mr. John L. Harper, Vice-President and Chief Engineer, Niagara Falls Power Company. The paper was illustrated by lantern slides and moving pictures. Attendance 225.

Denver.—May 21, 1921, Gas & Electric Company's Assembly Hall. Annual meeting and election of officers as follows: Chairman, Burton C. J. Wheatlake; Vice-Chairman, Edward A. Phinney; Secretary-Treasurer, Robert B. Bonney. The Chairman then introduced Professor L. D. Crain, of the Colorado Agricultural College, who spoke very interestingly and instructively on the subject of Electricity and Machinery on the Farm. Attendance 15.

Indianapolis-Lafayette.—May 27, 1921. Subject: "Inductive Interference." Speaker: Professor R. V. Achatz, of Purdue University. Attendance 55.

Ithaca.—May 6, 1921, Franklin Hall. Subject: "Alternating-Current Automatic Block Signaling." Speaker: Mr. S. M. Day, of the General Railway Signal Company. Attendance 50.

Madison.—April 27, 1921, Engineering Building, University of Wisconsin. Subject: "Problems in Connection with Extending Electric Service to Prospective Consumers." Speaker: Mr. J. N. Cadby. Attendance 30.

May 26, 1921, Engineering Building, University of Wisconsin. Election of Mr. C. B. Hayden as Chairman for 1921-22. Subject: "The Maintenance and Operation of High-Voltage Lines." Speaker: Mr. E. J. Kallevang, of the Wisconsin Power, Light and Heat Company. Attendance 20.

Minnesota.—April 29, 1921, Elks Club, St. Paul. Dinner followed by a talk by Mr. R. A. Lundquist, U. S. Department of Commerce, on his investigation of electrical trade conditions in the Orient and Africa. After the meeting an inspection trip was made of the St. Paul Gas Company's automatic substation for light and power in the Hamm Building. Attendance 50.

Pittsburgh.—May 10, 1921, William Penn Hotel. Subject: "Protective Relays." Speaker: Mr. L. N. Crichton, of the Westinghouse Electric & Manufacturing Company. The talk was illustrated by lantern slides and experimental tests on relays, and was devoted to the use of relays in securing continuity of service in power systems. Attendance 125.

Pittsfield.—May 31, 1921, General Electric Company's Auditorium. Smoker, during which District Attorney Charles H. Wright spoke on "Personal Rights Under the Constitution." Refreshments were served. Attendance 210.

Providence.—June 10, 1921, Providence Engineering Society Rooms. Annual meeting and election of officers for 1921-22 as follows: Chairman, Nicholas Stahl; Vice-Chairman, F. C. Freeman; Secretary-Treasurer, F. N. Tompkins. The new Chairmen, Mr. Nicholas Stahl, gave a very interesting and instructive talk on "Experiences in the Burning of Fuel Oil." Much of the subject matter pertained to the methods and apparatus used at the Narragansett Electric Lighting Company Station, one of the largest oil-burning stations in the East. Attendance 50.

St. Louis.—May 25, 1921, Engineers' Club. Business meeting, followed by a talk by Mr. W. F. Gaphart, of the School of Commerce, Washington University, on "Financing Public Utilities." Attendance 47.

San Francisco.—April 29, 1921. Subject: "A Variable Voltage Railway Converter Substation." Speaker: Mr. J. E. Woodbridge. Attendance 140.

Schenectady.—May 20, 1921, Edison Club Hall. Subject: "Engineering as Applied to Investments." Speaker: Mr. R. J. McClelland, Investment Banker, New York City. Attendance 155.

Seattle.—May 17, 1921, Arctic Club Assembly. Business meeting and election of officers as follows: Chairman, Mr. J. P. Growdon; Secretary, Mr. E. S. Code. Mr. R. F. Wensley, of the Westinghouse Elec. & Mfg. Co., gave a very interesting talk on "Automatic Substations as Applied to Power Railway, Industrial and Mining Applications." The talk was illustrated by lantern slides showing the first automatic substation, more recent installations and diagrams of control equipment. Views were also shown of the automatic substation just completed for the Northwest Traction Company at Martha Lake. Attendance 95.

Toronto.—April 29, 1921, Physics Building, Toronto University. Subject: "Illumination." Speaker: Mr. W. D'A. Ryan, of the General Electric Company. The subject was divided into four principal parts: The History of Artificial Illumination, The Illumination of the Panama-Pacific Exposition, Spectacular and Pageant Lighting, and Intensive Street Lighting. The lecture was built up around a set of three hundred of what are probably the finest lantern slides ever projected in Toronto. Mr. Ryan expanded on the subject matter of the slides as they were shown, and gave very interesting data as to the intensities of illumination, the types of illuminants and the cost of installation. Attendance 350.

May 13, 1921, Engineers' Club. Business meeting and election of officers as follows: Chairman, W. P. Dobson; Secretary, P. A. Borden; Executive Committee, Messrs. Schwenger, Chubbuck, Leacock, Anderson, Fleming and Henderson. After the business of the evening a short informal talk on the Queenston Chippawa Development of the Hydroelectric Power Commission was given by Mr. E. T. J. Brandon. The talk was liberally illustrated and served to give those present a very clear idea of this great work. Attendance 83.

Urbana.—May 18, 1921. Business meeting and election of officers for 1921-22 as follows: Chairman, E. H. Waldo; Vice-Chairman, C. L. Conrad; Secretary-Treasurer, H. A. Brown. Attendance 17.

Utah.—May 27, 1921, Commercial Club. Election of officers for 1921-22 as follows: Chairman, Paul P. Ashworth; Secretary, C. R. Higson; Junior Past Chairman, J. F. Merrill; Executive Committee, Messrs. H. W. Clark, J. A. Kahn, Robert Miller and W. A. Moser. Subjects: "Outline of Einstein Theory" by Dr. Orin Tugman, of the University of Utah; "Bonneville Irrigation Project" by Mr. O. McDerwith. Attendance 55.

Vancouver.—April 15, 1921. Subject: "High-Tension Transmission in British Columbia." Speaker: Mr. J. Muirhead, Inspector of Electrical Energy for the Province of British Columbia. Attendance 27.

May 6, 1921. Subject: "Electrical Power in Pulp and Paper Mills." Speaker: Mr. T. H. Crosby. Attendance 26.

Worcester.—May 10, 1921, Worcester Tech. Subject: "Modern Photography." Speaker: Mr. Arthur Palme. The lecture was illustrated with seventy slides, twenty of which were in natural colors. A one-reel film entitled "Revelations" showing the history of X-Rays and some actual X-Ray Motion Pictures concluded the lecture. Attendance 155.

PAST BRANCH MEETINGS

Armour Institute of Technology.—May 20, 1921. Election of officers as follows: Chairman, Robert P. Burns; Secretary, L. C. Grube; Treasurer, Eugene Mueser. Attendance 22.

University of Cincinnati.—May 24, 1921. Subject: "Ball Bearings." Speaker: Mr. A. A. Van Pelt, E. E. Attendance 86.

Clemson College.—May 10, 1921. Subject: "Troubles on the High-Voltage Lines." Treated by: Messrs. Fowler, Gower and Miley. "Current Events" by Mr. W. P. Tyler. Attendance 52.

University of Colorado.—May 12, 1921. Election of officers for 1921-22 as follows: Chairman, T. D. Sylvester; Secretary, F. D. Doolittle; Treasurer, Ivan Mauntel; Junior Committee, Messrs. Keller and Rankin. Professor W. C. Du Vall spoke on "History and Development of the A. I. E. E." Attendance 28.

Iowa State College.—May 11, 1921. Subject: "Electrical Slide Rules and Short Cuts in Electrical Computations." Speaker: Professor Edwin Kurtz. Advertising calculators and graphical charts were distributed and their use explained. Attendance 59.

May 25, 1921. Subject: "Fan Design and the Industrial Application of Air." Speaker: Mr. J. H. O'Brien, District Manager, for the American Blower Company, Indianapolis. Attendance 25.

June 1, 1921. Smoker. Professors Paine and Kurtz gave short talks. Mr. L. V. Bryan, Senior student, spoke on "Leaving School as a Senior." Messrs. Martin, Wilkins, Jeffers, Brown and Edaburn, Junior students. gave a mock faculty meeting of the Electrical Engineering Faculty. Refreshments were served. Attendance 93.

University of Iowa.—May 2, 1921. Talks were given by Mr. W. Reilly on "Einstein Theory" and Mr. W. C. Brandes on "Testing of Watthour Meters." Attendance 28.

May 6, 1921. Joint meeting of the various engineering branches. Subject: "Steam Power Plants." Speaker: Professor Fleming. Attendance 75.

May 16, 1921. Subjects: "Electrification of Railroads" by Mr. H. Shore; "Engineering in Foreign Countries" by Mr. V. Varbedian; "Power Distribution" by L. Rohret. Attendance 30.

Kansas State College.—April 25, 1921. Subjects: "Organization of the Commonwealth Edison Company" by Mr. M. C. Watkins; and "The Size, Movement and Force of Electrons" by Professor J. L. Brennenman. Attendance 30.

May 9, 1921. Subject: "Automatic Signal from a Railway Fireman's Viewpoint." Speaker: Mr. R. M. Crow. Attendance 14.

May 23, 1921. Subject: "Publicity Utility Investments." Speaker: Mr. Arthur Groesbeck, of the Rocky Ford Milling & Power. Attendance 31.

Lehigh University.—May 16, 1921. Election of officers as follows: Chairman, E. F. DeTurk; Vice-Chairman, G .M. Brumbaugh; Secretary, W. F. Tait; Treasurer, E. H. Snyder. Subject: "Recent Practise in Telephone Construction." Speaker: Mr. Frederick Galbraith, of the A. T. &. T. Co. Attendance 41.

University of Maine.—May 17, 1921. Subject: "Development of the Automatic Substation." Speaker: W. C. Plummer, President of the Branch. Attendance 9.

Massachusetts Institute of Technology.—May 17, 1921. Banquet. Election of officers for 1921-22 as follows: Chairman, L. R. Culver; Vice-Chairman, A. W. Milliken; Secretary, T. W. Codding; Treasurer, C. L. Maltby. Mr. C. T. Edgar, President, Boston Edison Company, spoke on the new coastwise superpower line; Dr. Elihu Thomson spoke on lightning phenomena and the Aurora Borealis. Attendance 100.

University of Michigan.—May 16, 1921. Election of officers for 1921-22 as follows: Chairman, F. D. Johnston; Vice-Chairman, W. E. Cook; Secretary, A. J. Martin; Treasurer E. W. Folsom. Attendance 11.

May 24, 1921. Mr. H. P. Schienberg, of the Western Electric Company, gave the talk of the evening, which covered the production of line poles and crossarms and was illustrated by six reels of moving pictures. The pictures were taken in the northwestern part of the country. This was a joint meeting with the Forestry Students. Attendance 77.

Montana State College.—May 11, 1921. Lecture by Mr. A. D. Stewart on Westinghouse activities. Attendance 48.

May 13, 1921. Electrical show. Attendance 908.

May 18, 1921. Moving pictures, Westinghouse films. Attendance 409.

University of North Carolina.—May 27, 1921. Election of officers as follows: Chairman, R. M. Casper; Vice-Chairman, C. U. Smith; Secretary, R. G. Koontz; Treasurer, J. R. Pursur, Jr. Attendance 48.

Ohio Northern University.—May 9, 1921. Election of officers as follows: Chairman, L. A. Kille; Vice-Chairman, H. D. Farnsworth; Secretary, I. W. Knapp; Treasurer, D. J. Wolfe. Talks by the Professors. Refreshments were served. Attendance 38.

Ohio State University.—May 20, 1921. Illustrated lecture on "Industrial Control Devices" prepared by the General Electric Company. Attendance 20.

University of Oklahoma.—May 18, 1921. Election of officers as follows: Chairman, Wesley Seifert; Vice-Chairman, Cecil Roush; Secretary, H. V. Thornton; Treasurer, A. B. Munson; Reporter, Virgin Pendleton. Attendance 53.

Oregon State College.—May 5, 1921. Election of officers for 1921-22 as follows: Chairman, Walter D. Olson; Vice-Chairman, Geo. Drewitt; Secretary-Treasurer, Clinton T. Hurd; Publicity Manager, Sidney Caldwell. Three reels of motion pictures entitled "The Benefactor" were shown after the meeting. Attendance 29.

Purdue University.—May 10, 1921. Election of officers for 1921-22 as follows: Chairman, N. C. Pearcy; Vice-Chairman, C. R. Hanna; Secretary, F. R. Finehout; Treasurer, S. J. Spurgeon. A six reel film on the manufacture of wood poles and wood conduit was shown. Attendance 44.

May 18, 1921. Mr. M. A. Putt, of the General Electric Company, gave a talk and demonstration of the "Pyrotip." Attendance 32.

Virginia Military Institute.—May 24, 1921. Subject: "Manufacture of the Mazda Lamp and Production of Artificial Light," with a Lighting Display. Speaker: Mr. J. G. Henninger of the Fostoria Sales Division National Lamp Works General Electric Company. Attendance 73.

University of Virginia.—May 11, 1921. Election of officers for 1921-22 as follows: Chairman, M. M. H. Morgan; Secretary-Treasurer, Mr. G. L. Goudy; Program Committee, Professor Rodman and Messrs. Forrest, Wingfield. Attendance 25.

State College of Washington.—May 13, 1921. Subject: "Electrical Measurements in Superheated Steam Research." Speaker: Professor A. R. Nottingham. Attendance 21.

University of Washington.—May 10, 1921. Subject: "Diesel Engines." Speaker: Mr. George S. Wilson. Attendance 28.

West Virginia University.—May 16, 1921. Subjects: "Hydroelectric Power for Industrial Purposes" by R. M. Hanks; "Repairing and Rewinding Armatures" by J. and L. Hark; "The Development of Radio Telegraphy" by A. C. Price; "The Vacuum Tube as a Generator" by W. D. Stump. Attendance 15.

University of Wisconsin.—May 3, 1921. Subject: "Signal Communication Methods." Speaker: Mr. C. T. Schrage. Attendance 18.

May 18, 1921. Business meeting, followed by a paper on "Electric Ship Propulsion," read by E. D. Johnson. Attendance 22.

May 25, 1921. Election of officers for 1921-22 as follows: Chairman, R. H. Herrick; Secretary-Treasurer, H. L. Rusch. Attendance 12.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

RECENT GRADUATES in Engineering Courses. Location New York City. X-564.

GRADUATE ELECTRICAL ENGINEER between 30-40 years. Should have gas and street R. R. experience as well as power sales. Location New York State. X-576.

YOUNG MAN acquainted with the electrical trade in New England to solicit business for repairing and recalibrating meters. Location Mass. X-590.

RECENT TECHNICAL GRADUATE for instructor in Electrical Engineering. Opportunity to pursue graduate work. Give references and details regarding technical and personal qualifications. X-596.

EASTERN TECHNICAL SCHOOL has opening on its teaching staff for instructor in Physics and Elementary Electricity. Young man, graduate of a four year Electrical or Mechanical Engineering Course with some practical or teaching experience preferred. The opportunity for advancement excellent. Reply stating age, education and training, experience and salary desired. Location Boston, Mass. X-604.

ENGINEER who has had experience in operating stationary oil engines, preferably the De La Vergne type. Prefer a single man. Location South America. X-613.

EASTERN TECHNICAL SCHOOL has opening for instructor in electrical machinery laboratory. Young men, graduates of a four years electrical or mechanical engineering course with some practical or teaching experience preferred. Opportunity for advancement excellent. Reply stating age, education and training, experience and salary desired. Location Boston, Mass. X-622.

ASSOCIATE PROFESSOR, or professor of electrical engineering, who will be responsible for laboratory courses handling about sixty juniors and fifteen seniors in a well developed laboratory. Should be prepared also to teach fundamental courses in direct currents and introductory alternating currents. Must be a man with both teaching and practical experience; a man with experience in a first class college laboratory is necessary. Location North West. X-628.

INSTRUCTOR in electrical engineering to handle, principally, laboratory courses. Must have had experience as an assistant, or instructor, in a good laboratory. Additional testing experience with a manufacturing company is desirable. Location North West. X-629.

INSTRUCTOR to serve in steam, gas and material testing laboratories. Should be a man of some experience in a good mechanical engineering laboratory. Location North West. X-630.

ASSISTANT PROFESSORS OF ENGINEERING DRAWING in a well-established State and Federal supported polytechnic institute wanted. Applicant must be thoroughly competent to teach any or all of the subjects dealt with in French's Engineering Drawing. Assurance of promotion to full professorship to properly qualified men. Location South. X-632.

DESIGNER of induction motors (not fractional horsepower) and familiar with their applications and manufacture for a successful

medium-sized company at present manufacturing electrical machinery. Both experience and initiative required. Position is attractive and permanent. In framing application, please state in detail character and extent of engineering, manufacturing, and commercial knowledge in relation to induction motors. Location New York. X-633.

SALES ENGINEERS. Must have good personality and know architects and builders in these localities. Elevator experience desirable. Application by letter only. Position will be open in two months. Location New York City and Middle West. X-637.

YOUNG PROGRESSIVE ENGINEER with some experience in design of air and oil-brake types of circuit breakers. Location Penna. Application by letter. X-638.

SALESMAN. In sales Department of old established manufacturing concern man about thirty to thirty-five years of age. One with engineering and sales experience preferred, to operate from Chicago office traveling the state of Wisconsin and the city of Chicago, about half time in each. Answer with complete details, including salary desired. X-643.

SALES. In Chicago branch of a substantial New York manufacturing concern, young man about 27 to 30 years of age, college trained preferred. A year or two successful sales experience would be additional qualification. Territory to be covered will be city of Chicago and some outside territory. Will be patient with the right man while he is learning. Please reply with full details as to education, experience and salary desired. X-644.

PROFESSIONAL DRAFTSMEN graduates of reputable engineering institutions who have had not less than five years work in the drafting rooms of large manufacturing concerns for university in South. X-647.

TECHNICAL GRADUATE who believes he could sell advertising. Prefer man who has been identified with the activities of a college, for example, in managing or assisting in the management of one of the teams or societies. Location New York City. X-652.

ELECTRICAL DRAFTSMEN, 5 or 6, in connection with preparing plans and specifications for various classes of electrical installations. Majority of the work will consist of electric hoist installations both induction motor and d-c. motor drive; power plant; transmission line and substation installations and in some instances electric pumping. Location Pa. X-654.

ELECTRICAL CONTRACTING COMPANY, well established, doing mostly public and factory work, desires thoroughly capable and experienced man to act as job foreman on construction work for a time with the idea of becoming general foreman later on, if found possessed of requisite ability. Splendid opportunity for right man. Technical graduate preferred, but man without college education will be considered. Location near New York City. X-655.

INDUSTRIAL ENGINEER to be in charge of large boiler shop. Must have boiler shop experience. Must be diplomatic, tactful, and a good executive. Application by letter only. Only engineer with broad experience will be considered. X-659.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER of 1917, desires work in field of electrical engineering, telephony or radio. Has had approximately one year's experience in each. Desires permanent work with a good chance for advancement. Single. Prefer Middle West. Available early in July. E-2733.

CHIEF OPERATING ENGINEER or mechanical superintendent with broad experience in safe and economical operation, maintenance of electric light, power and refrigerating plants; also large factories and buildings having 1st class engineers and electrician licenses. At present holding similar position, desires to make a change location anywhere before August 1st. E-2734.

MECHANICAL ENGINEER, age 22; single, graduate Stevens Institute of Technology, having about two years varied electrical experience, desires position in electrical engineering work preferably with consulting electrical engineering or electrical contracting concern, located near New York City where individual merit will be rewarded by advancement. Available in about two weeks notice. E-2735.

ELECTRICAL ENGINEER, age 36; seven years assistant professor of electrical engineering in prominent technical school in New York; very broad experience including isolated power plant management, testing and designing of electrical machinery, "radio" work, power distribution. Member A. I. E. E., salary $4000. E-2736.

GRADUATE ELECTRICAL ENGINEER, eleven years commercial, engineering and sales experience, available at once. Has been in executive charge of large engineering department of public utility. Has also been sales engineer. Responsible executive engineering or business position desired; preferably Central States. E-2737.

MECHANICAL ELECTRICAL, practical and executive engineer. Inventive ability, twenty-five years practical and executive experience with mining, marine, estate, steam, diesel, gas, oil, cars, refrigeration, oxyacetylene, plumbing, heating, ventilation, compressing. Experienced in every branch of trade from designing to operating. Secondary and technical education. Available 14 days notice. Offers solicited. E-2738.

ELECTRICAL ENGINEER, seven years experience in general engineering and seven years on design of small and medium sized d-c. and a-c. motors and generators, some teaching experience. Desires position as consulting or designing engineer. Developed motors and generators for nearly all industrial applications. Can furnish references showing high grade mathematical and analytical ability. Will consider teaching, electrical engineering or mathematics. E-2739.

RESEARCH ENGINEER, six years experience in electrical and mechanical laboratory research and development, including fifteen months development and service work on automobiles and equipment. Now employed. College graduate, 1915. Associate A. I. E. E. Available on short notice. Eastern States preferred. E-2740.

ERECTING ENGINEER, age 38; twelve years experience in erection and maintenance of steam and hydroelectric machinery and equipment, in connection with power, mines and mills in the States, Alaska, and foreign countries, desires connection as erecting and maintenance engineer on hydroelectric equipment. No objection to foreign work. E-2741.

ELECTRICAL ENGINEER, graduate Univ. of Mich. Associate A. I. E. E. Eight years experience covering construction, operation and maintenance of high-tension generating stations, substations, installation of factory equipment and a year of G. E. test, wishes responsible position with engineering, manufacturing or light and power company. Location U S. A. or abroad. E-2742.

ELECTRICAL ENGINEER. Age 24; married. Six years experience in practical and technical engineering. Two years experience hydroelectric engineering. Four years experience electrical testing, wiring, operating, installation of power panels and all kinds of electrical repairing. Best references. Assoc. A. I. E. E. Available immediately. Not looking for large salary. E-2743.

ENGINEER AND EXECUTIVE. Fourteen years practical experience in the design, construction and operation of engineering structures and industrial plants, holding positions as general superintendent, and engineer of works. Technical graduate mechanical engineering, 1907, desires position requiring high ability and hard work but offering opportunity for advancement. E-2744.

GRADUATE ELECTRICAL ENGINEER, age 25; married. Desires connection with concern where native ability, initiative and hard work will be appreciated. Three and a half years experience on machine layout, transmission and substation design. Salary of secondary importance. Employed at present. E-2745.

ELECTRICAL ENGINEER, age 36; single. Ten years experience in power station design, construction, operation and industrial engineering. Assoc. A. I. E. E. Extensive executive and purchasing experience. Desirous of entering engineering sales field or executive position. Salary $3500-5000. Available at once. E-2746.

ELECTRICAL LABORATORY ENGINEER. Twelve years experience in electrical and magnetic measurements and research work in laboratories of several of largest electrical companies, including General Electric, desires responsible position where technical knowledge on these subjects is essential. Age 34; present salary $2600; eastern location preferred. E-2747.

GRADUATE ELECTRICAL ENGINEER, age 37; having been in charge of the transmission and distribution systems of large Eastern Railway, now open for position in above mentioned line, or as manufacturers' salesman. E-2748.

ELECTRICAL MECHANICAL INDUSTRIAL and designing engineer; age 42; university graduate; able executive. Fifteen years, shop, office and field experience, with large industrial engineering and manufacturing companies; in estimating, engineering economics, design, construction and equipment of power plants, substations and factories. Salary in proportion to responsibilities. E-2749.

ELECTRICAL ENGINEER. American; age 33. Technical graduate 1911. Electrical manufactory testing, engineering and commerical experience. Several years practical work on installation, operation and maintenance of heavy traction equipment steam railroad electrification. Services as engineer offered at reasonable rate on new projects of this nature. E-2750.

GRADUATE ELECTRICAL ENGINEER, age 27; married. One year with large electric railway and light company, one year business experience. Desires position with engineering, manufacturing or light and power company. Assoc. A. I. E. E. E-2751.

INDUSTRIAL ENGINEER, technical, mechanical, electrical engineer, experienced in factory organization, operation, management. Modern methods of production control (routing, planning, scheduling), storeskeeping, determination, cost systems. Extensive practical experience as production manager of factories using methods employed by Messrs. Gantt, Barth, Baker and Taylor. Completing systematizing plant employing 3000; capacity production manager. E-2752.

EXECUTIVE ENGINEER, Member A. I. E. E. Yale graduate, desires interview with house of recognized reputation in Philadelphia, New York or New England. Eleven years experience covering broad field, in charge of electrical design and construction, and general building work. Several years training in all phases of operating. Age 31, married. E-2753.

ELECTRICAL ESTIMATOR AND ENGINEER, technical education. Fourteen years experience in building construction as mechanic, foreman, draftsman, engineer, and electrical estimator. Member of Chicago Electrical Estimators Association, Assoc. A. I. E. E. E-2754.

ENGINEER, B. S. in E. E. Associate A. I. E. E. age 25; single. Desires position in engineering or operation department. One year G. E. test, two years general engineering, tests, installations, and data. Present employed. Available after July 31st. E-2755.

ELECTRICAL ENGINEER, age 23; single; graduate California Inst. of Technology, 1920. One year's experience on General Elec. Co. test. Desires position with engineering, manufacturing or power company with opportunity for experience and advancement, or would like position as instructor in electrical engineering at some technical college. Available on short notice. Location immaterial. E-2756.

ELECTRICAL ENGINEER, Graduate Penn. State College; age 24; married. Desires connection with engineering, manufacturing or light and power company, where a hard working young man may be assured advancement. About nine months experience. Location preferably Pennsylvania. Available Sept. 1st. Member A. I. E. E. E-2757.

MECHANICAL AND POWER ENGINEER, age 29; single, technical graduate, B. S. and M. E. Seven years experience along broad lines, chemical manufacturing, machine shop metallurgy, sugar engineering, industrial and power plant practise, operation, layout, design, calculations, steam, water, air heating and distribution, research, etc. Has business and executive ability and can handle men; desires connection as mechanical engineer or in similar responsible position. E-2758.

TECHNICAL GRADUATE, B. S. degree in electrical engineering; age 22; single, desires connection with engineering, manufacturing or power company. One year's commercial and one year's technical experience. Work along commercial lines considered. Member A. I. E. E. Available immediately. E-2759.

ELECTRICAL AND MECHANICAL ENGINEER and executive, eighteen years experience in design, construction and operation of power plants and substation equipments, desires change. Age 42; married. Present salary $4100. Member A. S. M. E.; Assoc. A. I. E. E. E-2760.

ELECTRICAL ENGINEER, Assoc. A. I. E. E age 31, twelve years experience in engineering and construction, covering responsibility of supervising estimating, and laying out work, desires position affording opportunity in this field. E-2761.

ELECTRICAL ENGINEER, technical graduate; age 27; three years experience with large electrical concern in development and design of small motors of the splitphase, repulsion-induction polyphase, and two-pole d-c. types. Familiar with small motor application. Desires position with concern in which one can develop with the concern and where there would be excellent opportunities for the right man. Assoc. A. I. E. E. E-2762.

PROFESSOR OF ELECTRICAL ENGINEERING at State Institution desires change. Writer on technical subjects and practical engineer. E-2763.

ELECTRICAL ENGINEER, sixteen years experience with consulting engineer, with manufacturing concern and with Navy, desires part time work for consulting engineer or patent attorney. Designs, reports, experimental work. Capable of turning out careful and accurate work. Location in or near New York City. E-2764.

ELECTRICAL ENGINEER, age 36; seven years assistant professor of electrical engineering in prominent technical school in New York; very broad experience including isolated power plant management, testing and designing of electrical machinery, "radio" work, power distribution. Member A. I. E. E. Would like teaching position. Salary $3600. E-2765.

ELECTRICAL ENGINEER technical graduate; age 29; single. Two years practical experience in testing and layout work of starting and lighting systems for automobiles, also two years experience in export of machinery. Speaks and writes Greek and French. Assoc. A. I. E. E. Interested in estimating and contracting work also in installation of electrical machinery. Available immediately. E-2766.

TECHNICAL GRADUATE, B. S. in E. E. age 24. Three years testing and maintenance experience. Desires position with chance for advancement. Preferred location; central states. Available immediately. E-2767.

ASSOCIATE ELECTRICAL ENGINEER, Bureau of Standards, engaged for ten years in laboratory and field research and in dealing with public utility officials concerning electrolysis, desires responsible position with college of public utility. Several years college teaching experience and as engineer for G. E., W. E. and N. Y. Telephone Companies. E-2768.

ELECTRICAL ENGINEER. Nine years practise with sales experience, familiar with New York trade, desires to represent manufacturer of electrical or mechanical product in New York City. E-2854.

GRADUATE ELECTRICAL ENGINEER. Seventeen years' practical experience in manufacturing work and three years at teaching. Member A. I. E. E. Will consider teaching in central West or West at reasonable price. E-2859.

ELECTRICAL AND EXECUTIVE ENGINEER. Age 33; M. E. degree. Two years G. E. test and eight years in construction and operation of transmission lines, distribution systems, power plant, industrial installations, steam apparatus and piping. Experienced in handling men, organizing, purchasing, correspondence and writing reports and specifications. Position desired assistant manager, superintendent of operation or construction with power company or engineering capacity with industrial concern. E-2860.

ELECTRICAL ENGINEER. Age 27, experienced in electric railway and industrial plant engineering and electrical installations aboard ships, desires position in either sales or engineering departments of concern offering good chance for advancement. Now in charge of design work (electrical) for freighters and tankers. Available on short notice. Salary $3000. E-2861.

ELECTRICAL SUPERINTENDENT, technical training, twelve years experience design and supervision of hydroelectric stations, transmission lines, industrial plants including mechanical and concrete construction. Past five years charge hydroelectric construction in Latin America. Thorough knowledge Spanish, executive ability, tactful, no labor conditions too difficult. References furnished. Nominal investment to guarantee permanency if required. American; married; age 35. Minimum $5000. Available Sept. 1921, or Jan. 1922. E-2862.

TEACHERS AVAILABLE

The following list gives in each case school attended, age, etc. For more complete information address the Employment Service Bureau, giving key number.

University of Illinois; Penn. State College; age 36; married. Desires to teach any electrical engineering subjects except wireless and telephony. E-2769.

University of Michican, age 40; married. Taught mechanical drawing. Location Middle West or East. E-2770.

University of Michigan B. A., M. I. T.—B. S. Age 54; married. Desires to teach theoretical and practical electricity. Locations preferred Far West or Northern Atlantic States. E-2771.

University of Illinois; age 42; married. Location Central States. Salary $5000. E-2772.

University of Wisconsin; age 49; married. Eighteen years experience teaching electrical engineering subjects. Location West or Middle West. E-2773.

Polytechnic Institute, Brooklyn; age 45; married. Six years teaching experience. Desires position as professor, assistant professor or associate professor. Location U. S., East, Central or West. E-2774.

Ohio State Univ. Age 35; married. Four years, teaching experience, instructor and assistant professor. Location Central States. E-2775.

University of Wisconsin; age 36; married. Six years teaching experience, instructor and associate professor. Minimum salary $3600. Location Middle West, North or West. E-2776.

University of Wisconsin; age 30; married. Five years teaching experience, instructor and associate professor. Location Middle West. E-2777.

University of Wisconsin; age 41; married. Fifteen years teaching experience, instructor, head of department of physics. Location North or West. E-2778.

Ohio State University. M. E. E. E. Harvard A. M. Age 35; married. Three years teaching experience, instructor and professor. E-2779.

Iowa State College, age 36; married. Taught physics, mechanical drawing, direct and alternating-current electricity, trigonometry. Location Middle West. E-2780.

University of Arkansas, Ohio State University; age 35; married. Ten years teaching experience. Assistant professor and professor. Taught dynamo machinery, illumination, electric railway. Location Middle West or West. E-2781.

University of Texas, age 28; married. Three years teaching experience. Location South or Pacific Coast. E-2782.

University of Minnesota, age 39; married. Four years teaching experience. Desires position as assistant professor. Location West. E-2783.

University of Illinois, age 38; married. Eleven years teaching experience, instructor, assistant professor, associate professor, and professor. Desires position as professor of electrical engineering. E-2784.

Rose Polytechnic Inst.; age 35; married. Three years teaching experience. Desires position assistant or associate professor. Location Central States. E-2785.

Syracuse University, age 32; single. Desires position as professor or head of E. E. department. E-2786.

Rensselear Polytechnic Institute, age 37; married. Four years teaching experience, desires position as professor of electrical engineering and physics. E-2787.

Cooper Institute, age 44; married. Three years teaching experience. Location East. E-2788.

University of Maine. Age 43; married. Seventeen years teaching experience. E-2789.

Central Technical College. Age 42; married. Thirteen years teaching experience Desires position as professor of electrical engineering. E-2790.

Union University. Age 40; married. Taught electrical engineering continuously since 1908. Location South or East. E-2791.

Swarthmore College, age 33; single. Desires position associate professor. E-2792.

Leeds University, age 53; married. Desires position as assistant professor. Salary $5000. Location Eastern states. E-2793.

Massachusetts Inst. of Technology, age 36; married. Seven years teaching experience. Desires position as professor or head of E. E. department. Location North East or South West. E-2794.

Rutgers, Columbia, age 45; married. Fifteen years teaching experience. Instructor, assistant professor, professor of physics. Desires position as head of department in small technical school of state university. E-2795.

Columbia University; age 31; married. Desires position as professor or assistant professor teaching mathematical physics, dynamics, mechanical and automotive engineering subjects, design, etc., Location East or Middle West. E-2796.

Kansas State Agricultural College; age 37; married. Desires to teach power station of electrical engineering. Location Middle West. E-2797.

Stevens Institute of Technology; age 27; single. Taught mechanical drawing two years. Location Ohio, Indiana, or New York. E-2798.

Drexel Institute; age 26; single. Taught electricity, a-c. and d-c., mechanics, strength of materials, mechanical laboratory, testing and electrical laboratory. Location Pennsylvania, New Jersey or New York. E-2799.

Milwaukee University, age 21; single. No teaching experience. Desires position as laboratory assistant. Location East or Middle West. E-2800.

University of Nebraska. Age 29; single; Taught drawing, descriptive geometry, electrical engineering. Location U. S. E-2801.

M. I. T., age 31; married. Taught elements of electrical engineering, electrical laboratory, industrial applications of electricity. Location Middle West. E-2802.

Lewis Institute, age 24; single. Taught physics. Location Middle West. E-2803.

Cornell University, Univ. of Colo.; age 27; single. Two years teaching experience. Location preferred, West. E-2804.

Rice Institute; age 28; single. No teaching experience. Location Eastern States. E-2805.

Iowa State College, age 30; married. Desires position as instructor in mechanics, electrical theory, testing laboratory. (Mech. or E. E.) Location U. S. E-2806.

Ohio State University, age 30; married. Desires teaching position. Location West. E-2807.

Worcester Polytechnic Institute, age 35. married. Four years teaching experience; electrical measurements, laboratory, theory of alternating-current circuits and machines. Desires position as professor or associate professor. Location New England, Eastern Canada. E-2808.

University of Illinois, age 30; single. Desires teaching position. Location North West or Canada. E-2809.

University of California; age 27; married. No teaching experience. Desires position as instructor in elementary electrical engineering, physics, mathematics, or laboratory instructor in electrical engineering, tests, physics or steam. Location Middle West or West. E-2810.

Rutgers College; age 25; single. Desires teaching position; physics, tests, inspection, design, electrical railway. Location preferred, California. E-2811.

Yale University, age 24; single. Desires to teach electrical or mechanical engineering or physics. Location New England. E-2812.

New York Trade School, age 26; single. Desires position as electrical instructor at technical or trade school. Location preferred near New York City. E-2813.

Pennsylvania State College; age 24; married. No teaching experience. Location Middle or Western States. E-2814.

Pennsylvaniat State College; age 33; married. Six years teaching experience. Location East. E-2815.

University of Kansas, age 45; married. Ten years teaching experience, instructor and professor. Desires position professor of electrical or mechanical engineering. Would consider Orient; particularly China. E-2816.

Transylvania College, Univ. Ky., age 41; married. Ten years teaching experience. Head of department of electrical engineering. E-2817.

Technical University of Carlsruhe; age 33; married. Taught electrical engineering and physics. E-2818.

Pennsylvania State College; age 35; married. Taught course in electricity (night school). Would consider $1800 for 9 months. Location New England or North Atlantic States. E-2819.

University of Colorado; age 27; married. Taught physics, chemistry, electricity and mathematics. Location vicinity of New York. E-2820.

Clarkson Tech. Age 30; married. Teaching experience in Army only. Desires to teach mathematics and E. E. E-2821.

Lehigh University, age 28; single. Taught power engineering, thermo-dynamics laboratory. Location New York, New Jersey and Pennsylvania. E-2822.

Lehigh University, age 38; married. Taught electrical, engineering physics, anal. mech. Location East or North. E-2823.

University of Kansas, age 39; single. Taught elementary electrical machinery, illumination and central station design. Location West. E-2824.

University of Michigan; age 29; single. Taught mathematics and physics. Prefer location Pennsylvania or Michigan. E-2825.

University of Washington; age 26; single. Desires to teach mathematics (algebra, trigonometry, calculas). E-2826.

Syracuse University; age 39; married. Electrical engineering subjects eleven years. E-2827.

Purdue University; three years. Age 29; single. Assistant instructor electrical measurements. Location near New York City. E-2828.

Cornell University; age 40; single. Taught direct and alternating-current machinery, power plant design, illumination, switching control and protection. Location near New York City. E-2829.

Drexel Institute; age 23; single. Taught electrical subjects. E-2830.

Pennsylvania State College; age 34; single. Taught electrical engineering subjects. E-2831.

Cornell University; age 33; married. Taught electrical power, laboratory and design. E-2832.

Cornell University; age 33; married. Taught electrical engineering, sales engineering, export practise. Desires evening work. Location near New York City. E-2833.

Lehigh University; age 24; single. Taught mathematics, english and civics. Desires to teach electrical subjects or physics. Location Middle or Eastern part of Pa., Atlantic Coast. E-2834.

Union College; age 24; single. Taught electrical laboratory, analytical geometry, calculas. Location Pacific Coast or vicinity New York City. E-2835.

Michigan Agricultural College; age 33; married. Desires to teach text book, or laboratory work in direct or alternating currents. Location Southern Atlantic States. E-2836.

McGill University; age 35; single. Taught electrical engineering subjects. Location near New York City. E-2837.

Worcester Polytechnic Institute; age 43; married. Taught design of electrical machinery, general courses in a-c. and d-c. theory, electrical engineering laboratory etc. Desires position as head of department, teaching electrical design and other E. E. subjects. Location Eastern or South Western States. E-2838.

Polytechnic Institute of Brooklyn; age 22; single. Have been assistant in physics department. Desire to teach mathematics, physics, electrical measurements, etc. E-2839.

Pennsylvania State College; age 24; single. Desires to teach electrical laboratory, design, radio theory. E-2840.

Virginia Polytechnic Institute; age 23; single. Desires to teach physics and electrical engineering subjects. Location immaterial. E-2841.

Purdue University; age 25; single. Taught electrical design, laboratory, and radio. Location Middle West. E-2842.

Bucknell University; age 23; single. Taught mechanical drawing, physics, algebra, trigonometry, plane or solid geometry, arithmetic, surveying. Location Eastern U. S. E-2843.

McGill University; age 35; single. Desires to teach mechanics, physics, electricity, electrical design, laboratory. Location West. E-2844.

University of Wisconsin; age 25; married. No teaching experience. Location Central or Western U. S. E-2845.

Michigan State College; age 25; single. No teaching experience. Location Michigan or bordering states. E-2846.

Highland Park College; age 32; married. Taught physics, laboratory, electrical construction and maintenance. Location North Central U. S. E-2847.

University of Texas; age 24; married. Taught mathematics, mechanical drawing, radio theory. Location United States. E-2848.

North Carolina State College; age 32; married. Location South or West. E-2849.

Lawrence College, University of Wisconsin; age 36; married. Taught electrical engineering. Six years practical engineering experience. E-2850.

University of Michigan; age 24; single. Taught electrical engineering; physics and radio. Location Middle or Far West. E-2851.

University of Kentucky; age 22; single. Laboratory instructor. Location South West Ohio, or Kentucky. E-2852.

Pennsylvania State College; age 23; single. No teaching experience. Location immaterial. E-2853.

University of Illinois; age 26; single. No teaching experience. Desires to teach electrical engineering subjects of physics. Location preferred Middle West or West. E-2855.

University of Michigan; age 26; single. Taught drawing (descriptive geometry) assistant. Location North Central States. E-2856.

Rice Institute; age 27; married. Taught elementary and advanced electrical engineering. Location immaterial. E-2857.

Leland Stanford, Jr.; Age 34; single. Taught electric testing, power plant, research. Interested only in positions as professor or associate professor. E-2858.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JUNE 23, 1921

ACHESON, HARRY H., Plant Engineer, Bluefield Telephone Co., Bluefield, W. Va.

ADAMS, CHARLES H., Chief Electrical Engineer, Champion Engineering Co.; res., 222 E. Carmel St., Kenton, Ohio.

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SORENSEN, AUGUST G., Chief Operator, Detroit Copper & Brass Rolling Mills; res., 1466 McKinstry Ave., Detroit, Mich.

SPERRY, CHARLES S., Professor of Engineering Mathematics, University of Colorado; res., 1605 Hillside Road, Boulder, Colo.

SPROUL, S. M., JR., Meter Dept., Pennsylvania Utilities Co., Bangor, Pa.

STEPHENS, EARL W., Asst. Chief Lineman, Tel. & Tel. Depts., Pennsylvania System, (Central Region), 1502 Chamber of Commerce Bldg., Pittsburgh, Pa.

STEPHENS, HENRY R., Salesman, Independent Electric Machinery Co.; res., 311 S. Monroe, Kansas City, Mo.

STEWART, WILLIAM A., Toll Wire Chief, The Pacific Tel. & Tel. Co., 901 Telephone Bldg., Portland, Pre.

STRATHY, RALPH L. A., Student Apprentice, Canadian General Electric Co., Peterboro, Ont., Canada.

SULLIVAN, GEORGE R., Master Mechanic, Kennecott Copper Corp., Latouche, Alaska.

TARBELL, RAYMOND P., District Sales Manager, Cleveland Territory, The Lincoln Electric Co., Cleveland, Ohio.

TARR, FORREST E., Division Plant Supt., New England Tel. & Tel. Co., 220 Devonshire St., Boston, Mass.

TATEBE, TEIJI, Engineer, Kawakita Electric Co., 19, Shinsakanacho Kyobashi-ku, Tokyo, Japan

TAYLOR, WALTER D. K., Equipment Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., Norfolk, Mass.

THOMPSON, CLARENCE V., Electrician, Electric Storage Battery Co.; res., 3820 N. 15th St., Philadelphia, Pa.

TITUS, OLCOTT W., Salesman, Standard Underground Cable Company of Canada, Hamilton, Ont., Canada

TRIPP, JOHN P., Designer & Estimator, Dominion Bridge Co., Montreal; res., 758 St. Joseph St., Dixie Lachine, P. Q., Canada.

TROMBETTA, PANFILO, General Engineering Laboratory, General Electric Co.; res., 1241 Albany St., Schenectady, N. Y.

TURNER, MERTON H., Engineer & Switchboard Operator, Big Four Power Plant; res., 633 S. Main St., Bellefontaine, Ohio.

TWYFORD, G. T., Electrical Engineer, Hagerstown & Frederick Railway Co., Hagerstown, Md.

URE, ALBERT R., Meter Tester, Utah Power & Light Co., Bingham, Utah.

VISCHER, ALFRED, JR., Telephone Engineer, Western Electric Co., 463 West St., New York; res., 39 Childs Ave., Floral Park, N. Y.

VORONZOFF, PAUL I., Engineering Dept., New York Edison Co., 130 E. 15th St.; res., 179 W. 76th St., New York, N. Y.

WALD, DAVID, President & General Manager, Wald Electric Mfg. Corp., 248 N. 10th St., Brooklyn, N. Y.

WALTMAN, CHARLES B., Maintenance Man, Pennsylvania R. R., West Breakwater Power Plant; res., 1236 E. 83rd St., Cleveland, Ohio.

WEBB, JOHN B., Asst. Manager, Accessories Dept., Standard Underground Cable Co., 500 Westinghouse Bldg., Pittsburgh, Pa.

WEBSTER, DWIGHT S., Electrician, Atlas Crucible Steel Co., Dunkirk; res., Fredonia, N. Y.

WEIL, MABEL, Physicist in Charge, Radium Laboratory, Dr. Issac Levin, 119 W. 71st St. New York; res., 1362 Pacific St., Brooklyn, N. Y.

WEIR, PERCY G., Order Clerk, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Canada.

WELSMAN, THEODORE S., Draftsman, Hydro-Electric Power Commission of Ontario; res., 12 Walmer Road, Toronto, Ont., Canada.

WESTERVELT, ALBERT F., District Foreman, Rutherford Public Service Electric Corp. of N. J.; res., 203 Main St., East Rutherford, N. J.

WHARTON, GEORGE E., Manager, Apparatus Dept., Commercial Electrical Supply Co.; res., 4064 Mofflitt Ave., St. Louis, Mo.

WHEELER, ROY A., Outside Plant Engineer, Wisconsin Telephone Co.; res., 1468 Farwell Ave., Milwaukee, Wis.

WHITE, KENNETH C., Asst. Chief Lineman, Tel. & Tel. Depts., Pennsylvania System, (Central Region), 1502 Chamber of Commerce Bldg., Pittsburgh, Pa.

WIDMAN, JOHN G., Chief Electrician, American Lead Pencil Co.; res., 523 Park Ave., Hoboken, N. J.

WILLIAMS, RICHARD E., Draftsman, Commonwealth Edison Co., 72 W. Adams St.; res., 822 Lorel Ave., Chicago, Ill.

WILSON, MARION E., Service Engineer, Switchboard Division, Westinghouse Elec. & Mfg. Co., Atlanta, Ga.

WINTER, WILLIAM A., X-Ray Engineer, The Kny-Scheerer Corporation of America, 56-58 W. 23rd St., New York, N. Y.

*WINTHER, PETER C., Jr., Instructor, School of Engineering of Milwaukee; res., 174 Martin St., Milwaukee, Wis.

WOOD, BYRON M., Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., 52 Oak St., Stoneham, Mass.

WOOLEY, FRANK E., Electrician, In charge of Stator & Field Winding, Hunter Fan & Motor Co.; res., 163 W. 2nd St., Fulton, N. Y.

WOOLEY, WILLIAM C., Design Engineer, Transformer Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1340 Walnut St., Pittsburgh, Pa.

WURTS, ALDIS H., Attorney, M. B. & H. H. Johnson, 1009 American Trust Bldg., Cleveland; res., 1442 Clarence Ave., Lakewood, Ohio.

WYGANT, WALTER H., Chief Electrician Seamless Rubber Co.; res., 81 1st St. New Haven, Conn.

WYLD, CHARLES N., Draughtsman, Western Electric Co., 463 West St., New York, N. Y.; res., 604 Bloomfield St., Hoboken, N. J.

*YAMADA, HIDEO, Electrical Engineer, Engineering Dept., Tokiwa Co., Ltd.; res., 2 Nagasumi-Cho, Asakusaku, Tokyo, Japan.

YANAGIWARA, SAIJIRO, Electrical Engineer, Kyushu Hydro-Electric Co., Oita City, Kyushu, Japan.

ZBOYOSKY, WILLIAM J., Power Sales Dept., Penn. Power & Light Co.; res., 136 S. Madison St., Allentown, Pa.

ZIEGLER, TOBIAS F., Teaching Electrical Work, Rock Springs High School, Rock Springs, Wyoming.

ZUBICK, JOHN W., Research Dept., Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Total 285.

*Former enrolled students.

ASSOCIATES REELECTED JUNE 23, 1921

DAVIS, MAYNARD R., Dist. Service Manager, Westinghouse Elec. & Mfg. Co., 573 W. 2nd South, Salt Lake City, Utah.

LYMAN, VAN ALLEN, Electrical Engineer, Coast Rock & Gravel Co., San Francisco; res., Aromas, San Benito Co., Calif.

O'LEARY, JOHN JOSEPH, 21 Lincoln House, Basil St., S. W. 3, London, England.

PHELPS, HOWARD S., Technical Asst., Engineering Dept., Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

PRESTON, CHARLES R., Utility Engineer, Phoenix Utility Co., Allentown, Pa.

RICHMOND, CARL A., Lawyer, American Telephone & Telegraph Co., 195 Broadway, New York, N. Y.

TERVEN, LEWIS A., Electrical Engineer, Switchboard Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

WELD, HAROLD K., Sales Engineer, Standard Underground Cable Company of Chicago, 1548 Conway Bldg., Chicago, Ill.

MEMBERS ELECTED JUNE 23, 1921

ELMEN, GUSTAF W., Research Engineer, Western Electric Co., 463 West St., New York, N. Y.

ENGEL, NATHAN L., Supt. of Distribution Dept., Montreal Public Service Corp., 263 St. James St., Montreal, Que., Canada.

MYERS, RALPH E., Chief Engineer, Westinghouse Lamp Co., Bloomfield, N. J.

TAYLOR, THOMAS S., Research Physicist (Engineer), Westinghouse Elec. & Mfg. Co., Westinghouse Research Bldg., E. Pittsburgh, Pa.

TRACEY, ALBERT I., Chief Electrician & Asst. Manager, Cable Works, Johnson & Phillips, Ltd., Victoria Road, Charlton, London, S. E. 7, England.

WALMSLEY, HAROLD M., Engineer, The Post-Glover Electric Co., Cincinnati, Ohio.

WHEELER, EDMUND B., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

WHITE, WILLIAM M., Manager & Chief Engineer, Allis-Chalmers Mfg. Co.; res., 747 Summit Ave., Milwaukee, Wis.

WILSON, GOLDER P., Switchboard Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 209 South Ave., Wilkinsburg, Pa.

TRANSFERRED TO GRADE OF FELLOW JUNE 23, 1921

BURKETT, CHARLES W., Chief Engineer, Pacific Telephone & Telegraph Co., San Francisco, Cal.

CHUBB, LEWIS W., Manager, Radio Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

CONRAD, NICHOLAS J., Secretary-Treasurer & Manager, Schweitzer & Conrad, Inc., Chicago, Ill.

DAVIES, CHARLES E., General Traffic Superintendent, Canadian National Telegraphs, Toronto, Ont.

MORELAND, EDWARD L., Partner & Manager, Jackson & Moreland, Boston, Mass.

NEWBURY, FRANK D., Manager, Power Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

REED, HARRISON P., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

SMITH, ERNEST F., Superintendent of Substations, Commonwealth Edison Co., Chicago, Ill.

THORNTON, FRANK, Jr., Manager, Electric Heating Engineering Dept., Westinghouse Elec. & Mfg. Co., Mansfield, O.

WALLER, ALFRED E., Chief Engineer, Ward Leonard Electric Co., Mount Vernon, N. Y.

WEICHSEL, HANS, Chief Designing Engineer, Wagner Electric Co., St. Louis, Mo.

YOKURA, MORINOSUKE, Engineer-Captain, Chief of Electrical Engineering Bureau, Imperial Japanese Navy, Tokyo, Japan.

TRANSFERRED TO GRADE OF MEMBER JUNE 23, 1921

ANDERSON, E. R., Electrical Engineer, Supply Dept., General Electric Co., Schenectady, N. Y.

ATKINS, CHARLES G., Consulting Engineer, Chicago, Ill.

BELLINGER, W. F., Asst. Supt. Operation, Tests & Repairs, Atlanta Railway & Power Co., Atlanta, Ga.

BINGHAM, ALBERT R., Superintendent, Canadian Light & Power Co., Montreal, Que.

BRUBAKER, HENRY S., Construction Engineer, West Penn Power Co., Pittsburgh, Pa.

CASE, RALPH E., Works Manager, John Johnson Co., Brooklyn, N. Y.

CELLAR, GEORGE A., General Supt. of Telegraph, Pennsylvania System, Philadelphia, Pa.

CLEGG, T. HERBERT, Assistant to Otto M. Rau, Philadelphia, Pa.

DANIELS, RAYMOND S., Electrical Engineer, Washington Water Power Co., Spokane, Wash.

DAVIS, ERNEST W., Asst. Electrical Engineer, Simplex Wire & Cable Co., Cambridge, Mass.

FIELD, FRANK E., Electrical Engineer, Western Electric Co., New York, N. Y.

FLEMING, DAVID B., Asst. Electrical Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

FURUICHI, TATSUWO, Engineer Lieutenant-Commander, Imperial Japanese Navy, Tokyo, Japan.

GEE, PAUL M., Foreman, Electric Drafting Division, Brooklyn Edison Co., Brooklyn, N. Y.

GERHARDT, CARL L., Electrical Engineer, United Verde Copper Co., Clarkdale, Ariz.

GOLDBERG, MAXIMILIAN M., Inventor, National Cash Register Co., Dayton, O.

GRIMSLEY, A. H., General Manager, Virginia Western Power Co., Clifton Forge, Va.

HALL, MARTIN S., Superintendent, Electrical Dept., Mathieson Alkali Works, Saltville, Va.

HARBAUGH, WILLIAM M., Engineer, Lehigh Portland Cement Co., Allentown, Pa.

HARTSHORNE, WILLIAM B., Service Engineer, Public Service Electric Co., Newark, N. J.

HERSHEY, HARRY E., Telephone Engineer, Automatic Electric Co., Chicago, Ill.

HILL, ARTHUR ST. J., Associate Professor of

JAMES, HAMILTON D., Manager, Industrial Division, Westinghouse Elec. & Mfg. Co., Cincinnati, O.

JEFFERY, J. J., Asst. Electrical Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

KIDDER, HARRY A., Supt. of Motive Power, Interborough Rapid Transit Co., New York, N. Y.

KLAUDER, LOUIS T., Consulting Engineer, Philadelphia, Pa.

KNIGHT, ROBERT, Estimating Engineer, Canadian General Electric Co., Toronto, Ont.

Electrical Engineering, University of Maine, Orono, Me.

LEFEVER, ORLAND L., General Supt., Northwestern Electric Co., Portland, Ore.

LOBECK, ADOLPH J., Asst. Supt., Bronx District, N. Y. Edison Co., New York, N. Y.

McAFEE, W. KEITH, Foreman, Sunnyside Engine House, Pennsylvania Railroad, New York, N. Y.

MILBURN, WILLIAM R., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

NEBLETT, HERSCHEL W., Asst. Electrical Engineer, Steel & Tube Co. of America, Chicago, Ill.

NICHOLSON, CHARLES M., Supt., Electrical Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

PALMER, HARRY R., Vice-President & General Manager, Harrisburg Light & Power Co., Harrisburg, Pa.

REDING, HENRY W., Head of Electrical Dept., Atlanta Office, Lockwood, Greene & Co., Atlanta, Ga.

RICKWOOD, HAROLD A., Works Manager, Pirelli General Cable Works Ltd., Western Shore, Southampton, England.

ROMANOVSKY, CHARLES, Commercial Engineer, General Electric Co., Schenectady, N. Y.

SCHIEFER, HENRY J., Jr., President & Treasurer, Schiefer Electric Co. Inc., Rochester, N. Y.

SCHWARTING, HARRY F., Assistant to Chief Electrical Engineer, American Car & Foundry Co., St. Louis, Mo.

SKINNER, MERRILL E., Electrical Designing Engineer, Transformer Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

SNIFFIN, EDWARD H., Manager, Power Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

STEVENSON, FRANCIS L., Chief Electrical Engineer, International Harvester Co., Chicago, Ill.

THOMPSON, ROSS E., Manager, Deming Ice & Electric Co., Deming, N. M.

VANDERPOEL, WILLIAM K., General Supt. of Distribution, Public Service Electric Co., Newark, N. J.

WILLMANN, WILLIAM F., Electrical Engineer, Edison Electric Illuminating Co., Boston, Mass.

WOODRESS, JAMES L., Sales Manager, Century Electric Co., St. Louis, Mo.

WYATT, FRANCIS D., Electrical Engineer, Union Gas & Electric Co., Cincinnati, O.

YOUNG, H. W., President, Delta-Star Electric Co., Chicago, Ill.

RECOMMENDED FOR TRANSFER

The Board of Examiners at its meetings held May 13, June 10 and 16, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the secretary.

To Grade of Fellow

BAILEY, BENJAMIN F., Professor of Electrical Engineering, University of Michigan, Ann Arbor, Mich.

FORTESCUE, CHARLES L., Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HERZ, ALFRED, Engineer of Electrical Tests, Public Service Co. of Northern Illinois, Chicago, Ill.

LAWSON, CHARLES S., Section Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WYMAN, FRANK T., President, Packard Electric Co., Ltd., St. Catherines, Ont.

To Grade of Member

BAER, FREDERICK L., Contract Sales Engineer, Automatic Electric Co., Chicago, Ill.

BEATTYS, WILLIAM H., JR., Representative, Westinghouse Traction Brake Co., Chicago, Ill.

COLE, JAMES L., Asst. Superintendent, Westinghouse Elec. & Mfg. Co., Newark, N. J.

CROFT, TERRELL, Directing Engineer, Terrell Croft Engineering Co., St. Louis, Mo.

GUILDFORD, CHARLES T., General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

LAWSON, JOEL S., Sales Engineer, R. Thomas & Sons Co., New York, N. Y.

LEWIS, DONALD M., Secretary & Treasurer, General Manager & Chief Engineer, Livingston-Niagara Power Co., Avon, N. Y.

MARTIN, WILLIAM H., Dept. of Development and Research, American Telephone & Telegraph Co., New York, N. Y.

OSBORNE, CHARLES P., Supt. of Light & Power, Portland Railway Light & Power Co., Portland, Ore.

ROBBINS, ARTHUR H., Supt. of Distribution, Electric Light & Power Co. of Abingdon & Rockland, North Abingdon, Mass.

RUSSELL, HERBERT A., Designing Engineer, Toronto Hydro-Electric System, Toronto, Ont.

TERVEN, LEWIS A., Electrical Engineer, Switchboard Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

THAU, WALTER E., Engineer, Marine Section, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WAGNER, EFFINGHAM B., Electrical Engineer, Lehigh Valley Coal Co., Wilkes-Barre, Pa.

WELLS, JAMES H., Chief Electrical Draftsman, Brooklyn Edison Co., Brooklyn, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1921.

Ainsworth, Chester D., (Member), Boston, Mass.
Alexander, James P., (Member), New Haven, Conn.
Anderson, Idof, Worcester, Mass.
Angus, Roy F., New York, N. Y.
Attwood, Stephen S., Ann Arbor, Mich.
Beyersdorfer, Fred A., Brooklyn, N. Y.
Bucklin, A. H., Burley, Iowa.
Careless, George M., Philadelphia, Pa.
Carlson, Edwin L., San Francisco, Cal.
Chapleau, Dean D., Schenectady, N. Y.
Chatley, Charles C., Boston, Mass.
Cox, Harold J., New Haven, Conn.
Curtis, Edward C., Wichita, Kans.
Daley, Carl F., Arlington, Mass.
Dee, F. Kyrl, New York, N. Y.
De Remer, James S., Denver, Colo.
Dunmire, Russell P., (Member), Irwin, Pa.
Duste, Arthur W., Denver, Colo.
Earle, Ralph P., Philadelphia, Pa.
Elieson, Edwin E., Murray, Utah.
Fahning, Otto R., New York, N. Y.
Gillis, Melvin D., Erie, Pa.
Gordon, Bert E., Ogden, Utah.
Graner, George S., Hazleton, Pa.
Harris, Frank St. C., Deep Rock, Nova Scotia.
Hemingway, Harry A., Lynn, Mass.
Hennefer, Arthur McA., Salt Lake City, Utah.
Inouye, Noboru, Baltimore, Md.
Johnson, Chesley H., Philadelphia, Pa.
Jones, Frederic P., Grand Falls, Maine.
Kaelber, J. George, Rochester, N. Y.
Killebrew, Emmet S., (Member), Albany, Ga.
Kissel, Walter P., Ogden, Utah.
Knott, Charles E., San Francisco, Cal.
Kuhns, John H., Cleveland, Ohio.
Kulka, Eugene R., Brooklyn, N. Y.
Langford, Wilbur H., Preston, Idaho.
Latorre, Robert J., Schenectady, N. Y.
Liunge, Paul, New York, N. Y.
Lundberg, Fred L., Salt Lake City, Utah.
Marasigan, Vivente, Manila, P. I.
Marion, Frederick R., New York, N. Y.
Marti, Othmar K., Milwaukee, Wis.
Morton, Thomas Q., Prairie View, Texas.
Mueller, Edwin, St. Louis, Mo.
North, John R., Sawtelle, Cal.
McCormick, Rollin D., Hawthorne, Ill.
Pelton, Willis H., Erie, Pa.
Pratt, Chester C., Salt Lake City, Utah.
Randall, Ernest G., Montour Falls, N. Y.
Rees, Edward H., (Member), Alton, Ill.
Reynolds, Lewis C., (Member), Geneva, N. Y.
Richards, Otho C., St. Louis, Mo.
Riggs, Oliver S., New York, N. Y.
Rose, Otto K., Detroit, Mich.
Rosenberg, Abraham, New York, N. Y.
Schamberger, Sanford O., Schenectady, N. Y.
Schiemer, Edward W., New York, N. Y.
Shanck, Roy B., New York, N. Y.
Smith, Leon E., (Member), W. Lynn, Mass.
Steck, M. M., Salt Lake City, Utah.
Stephens, William T., Milwaukee, Wis.
Taggart, Willard T., Philadelphia, Pa.
Taylor, Clarence M., Cleveland, Ohio.
Thompson, Earl L., Lancaster, N. Y.
Tomlinson, Carroll M., Pittsburgh, Pa.
Twyman, Neal, Boulder, Colo.
Van Norman, James W., James Island, B. C.
Veatch, James S., Mansfield, Ohio.
Wagner, George, New York, N. Y.
Waterman, John H., Boston, Mass.
Whitall, Charles W., Pawling, N. Y.
Wichman, Ralph D., San Francisco, Cal.
Wilch, Nole H., Beaver Dam, Ohio.
Williams, Jerome H., New York, N. Y.
Yates, Raymond F., New York, N. Y.
Total 76.

Foreign

Ashmore, Joseph, Manchester, Eng.
Baba, Kumeo, Tohokudaigaku, Sendai, Japan.
Butterworth, Alfred, (Member), Cawnpore, India
Freuchen, Thord H., Rancagua, Chile.
Krogh, Gunnar E., Kristiania, Norway.
Kuroyanagi, Kenichi, Oimachi, Tokyo, Japan.

Morishima, Teiichi, Sukegawa, Japan.
Niethammer, Friedrich, Prag 1, Bohemia.
Quinlan, Joseph M., Honolulu, T. H.
Reporter, Dara B., Thana, India.
Takao, Naosaburo, Sukegawa, Ibaragiken, Japan.
Tamagawa, Hisao. Ibaraki-ken, Japan.
Williams, Alec. D., Broken Hill, N. S. W., Aus.
Yokota, Chiaki, Sukegawa, Ibarakiken, Japan.
Total 14.

STUDENTS ENROLLED, JUNE 23, 1921

13458 Frech, A. Dewey, Pennsylvania State College
13459 Cheney, George L., Wentworth Institute
13460 Dobler, Henry C., Jr., Stevens Institute of Technology
13461 Hodgkins, Raymond L., Wentworth Inst.
13462 Sweet, Ralph G., Wentworth Institute
13463 Bateman, Gordon R., Toronto Central Technical School
13464 Flemming, Hartwell, Mass. Inst. of Tech.
13465 Reich, Herbert, Carnegie Institute of Technology
13466 Cooper, LeMar S., Pennsylvania State College
13467 Cushman, Robert W., Worcester Polytechnic Institute
13468 Hubbard, Fred, Toronto Central Technical School
13469 Seward, George M., Pratt Institute
13470 Strock, Reeve O., University of Wisconsin
13471 Anderson, Raymond D., Carnegie Institute of Technology
13472 Bird, Everett L., Ohio Northern Univ.
13473 Drewett George A., Oregon State Agr. College
13474 Lundy, Edwin L., Colorado Agr. College
13475 Burke, Francis E., Clarkson College of Technology
13476 Sloane, Alvin, Tufts College
13477 Van Giesen, Ira D., Pennsylvania State College
13478 Theel, Edward O. W., School of Engineering of Milwaukee
13479 Kreek, Louis F., Mass. Institute of Tech.
13480 Maitland, Thomas J., Worcester Polytechnic Institute
13481 Peterman, F. Karl, Mass. Institute of Technology
13482 Bauder, Walter W., Univ. of Alabama
13483 Perry, Kenneth R., Worcester Polytechnic Institute
13484 Rohret, Leonard C., State University of Iowa
13485 Ferre, Albert W., Stevens Institute of Technology
13486 Byrne, John A., Rensselear Polytechnic Inst.
13487 Smith Francis W., Pennsylvania State College
13488 Dalrymple, Edward R., McGill University
13489 Mimmo, Harry Rowe, Rensselaer Polytechnic Institute
13490 Rhodes, Earl D., Rensselaer Polytechnic Institute
13491 Schilling, Philip R., Rensselaer Polytechnic Institute
13492 McBride, Lyle E., University of Nebraska
13493 Earle, Richard T., Johns Hopkins Univ.
13494 Kadan, Gilbert F., Johns Hopkins Univ.
13495 Fischer, Joseph W., Stevens Institute of Technology
13496 Dambly, Harold A., Pennsylvania State College
13497 Hagertown, Walter C., Mass. Institute of Technology
13498 Steel, Frederick K., Montana State College
13499 Burleigh, Edward I., Worcester Polytechnic Institute
13500 Smith, Philip C., University of North Carolina
13501 Foote, William F., University of North Carolina
13502 Thomas, Robert V., Westinghouse Technical Night School
13503 Howe, Wilfred H., Worcester Polytechnic Institute
13504 Pixler, John, Ohio Northern University
13505 Eaton, Earle, Spring Garden Institute
13506 Moore, George F., University of Arkansas
13507 Larsen, James C., Oregon Agri. College
13508 McGee, Richard R., University of Kansas
13509 Schroeder, Louis L., School of Engineering of Milwaukee
13510 Crothers, Felix A., Carnegie Institute of Technology
13511 Stewart, Joseph, Newark Technical School
13512 Hobart, John P., Jr., University of Cincinnati
13513 Chen, Yuhan, Cornell University
13514 Wilson, David E., University of Colorado
Total 57.

OFFICERS OF A. I. E. E. 1920-1921

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A. W. Berresford

Junior Past-Presidents
Comfort A. Adams
Calvert Townley

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Charles Robbins
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C. E. Magnusson
E. H. Martindale
C. S. McDowell

Managers
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Wilfred Sykes
L. E. Imlay
F. F. Fowle
L. F. Morehouse
Walter I. Slichter
G. Faccioli
Frank D. Newbury
Harold B. Smith
James F. Lincoln
E. B. Craft

Treasurer
George A. Hamilton

Secretary
F. L. Hutchinson

A. I. E. E. COMMITTEES

(A complete list of the personnel of Institute committees will be found in the June issue of the Journal; and a list of the new committees to be appointed in August, for the administrative year beginning August 1st, will be published in the September issue.)

GENERAL STANDING COMMITTEES AND CHAIRMEN

Executive, A. W. Berresford
Finance, Charles Robbins
Meetings and Papers, W. I. Slichter
Publication, N. A. Carle
Coordination of Institute Activities, L. T. Robinson
Board of Examiners, Clayton H. Sharp
Sections, John B. Fisken
Student Branches, C. Francis Harding
Membership, E. H. Martindale
Public Policy, H. W. Buck
Law, H. H. Barnes, Jr.
Headquarters, Wm. A. Del Mar
Safety Codes, Farley Osgood
Code of Principles of Professional Conduct, George F. Sever
Standards, Dugald C. Jackson
Edison Medal, Comfort A. Adams
Research, F. B. Jewett

SPECIAL COMMITTEES AND CHAIRMEN

Geographical Divisions and Election Procedure, H. H. Barnes, Jr.
Superpower System, W. S. Murray

TECHNICAL COMMITTEES AND CHAIRMEN

Economics of Electric Service, Philip Torchio
Educational, C. E. Magnusson
Electrical Machinery, B. A. Behrend
Electrochemistry and Electrometallurgy, F. A. J. FitzGerald
Electrophysics, F. W. Peek, Jr.
Industrial and Domestic Power, A. G. Pierce
Instruments and Measurements, F. V. Magalhaes
Iron and Steel Industry, W. F. James
Lighting and Illumination, C. E. Clewell
Marine, Arthur Parker
Mines, Graham Bright
Power Stations, H. P. Liversidge
Protective Devices, D. W. Roper
Telegraphy and Telephony, Donald McNicol
Traction and Transportation, Charles S. Ruffner
Transmission and Distribution, E. B. Meyer

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives will be found in the June issue of the Journal and will be published again in the September issue.)

Council of the American Association for the Advancement of Science
American Bureau of Welding
American Committee on Electrolysis
American Engineering Standards Committee
American Engineering Council of the Federated American Engineering Societies
American Year Book Advisory Board
Board of Trustees, United Engineering Society
Engineering Foundation Board
Franco-American Engineering Committee
John Fritz Medal Board of Award
Joint Committee on Engineering Education
Joint Committee on Standard Thread for Insulators and Insulator Pins
Library Board of United Engineering Society
Electrical Committee of National Fire Protection Association
National Joint Committee on Overhead and Underground Line Construction
Engineering Division, National Research Council
Naval Consulting Board
Special Joint Committee on Determination of Power Factor in Polyphase Circuits
U. S. National Committee of the International Electrotechnical Commission
U. S. National Committee of the International Illumination Commission
Commission of Washington Award

A. I. E. E. SECTIONS AND BRANCHES

A complete list of the 42 Sections and 61 Branches of the Institute, with the names of the chairmen and secretaries, will be found in the June issue of the Journal and will be published again in the September issue.

// JOURNAL
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Vol. XL AUGUST, 1921 Number 8

Electric Propulsion of Ships

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THIS paper will deal primarily with the electric propulsion of large ships, and as illustrative of large ship drives, a description and some discussion will be given of the propelling machinery of the *U. S. S. Tennessee*. In order, however, to make certain general comparisons helpful to the discussion, it will be necessary to introduce to some extent all feasible types of propelling equipment.

It is believed to be generally recognized by those who have made a broad study of the situation that the type of drive best suited to a given ship depends upon the characteristics of the ship, its trade route, and the cargo to be carried. These factors are so diversified that no unqualified preference can be held for any one type of propulsion, or in other words, there is a proper field for all principal types of ship drives.

The following types and arrangement of power drives have been applied with more or less success:

1. Direct-connected reciprocating engine.
2. Direct-connected turbine.
3. Geared turbine.
4. Turbine electric with direct-connected motor.
5. Turbine electric with geared motor.
6. *Internal combustion engine, direct-connected.
7. *Internal combustion engine, geared.
8. *Internal combustion engine- or Diesel-electric using direct-connected motors.

The principal objections to the reciprocating engine are those incident to its poor economy, and to some extent its weight and space factors. This type of drive, however, will exist for some time to come, as it has obtained a high state of development, and is at the present time better understood by the operating engineers. It is felt, however, that this condition will be greatly overcome as soon as the engineers now under training have become acquainted with the newer types of drive.

The development of the direct-connected turbine has probably gone as far as can be expected. This type of drive is being discarded because of its poor performance, as both the propeller and the turbine are operated at speeds not adapted to the best operating conditions of either.

There have been numerous applications of the geared turbine drive, and although there have been some disappointments, the general results indicate that the geared turbine drive has come to stay and enjoy a field of its own.

The turbine electric drive using direct-connected motors is a perfectly logical and applicable type of propulsion. Owing to the economy of high-speed turbines, alternating current is found best suited as a-c. turbo-generators lend themselves very readily to high-speed operation. Two types of motors have been proposed and used, namely the induction type and the synchronous type. The synchronous motor drive has slight weight and cost advantages over the ordinary induction motor drive, for the reason that the unity power factor of the synchronous motor permits a smaller generator, and the synchronous motor is cheaper to build than the induction motor. On the other hand, the induction motor drive has maneuvering advantages as it requires less skill in handling and possesses much better starting torque characteristics. The economy of the two types should be about the same.

Turbine electric drive using geared motors will probably see very little more development as the speed reduction can be accomplished efficiently with direct connected motors without gears.

The internal combustion engine, direct-connected to the propeller shaft, has been applied with considerable success in European countries, and is being given considerable serious attention at the present time in this country. From the fuel consumption standpoint, the direct-connected Diesel drive is far superior to any type of steam drive, and is certain to enter an era of prosperity. When compared with Diesel electric drive, however, the fuel economy advantages of the direct Diesel drive are small and other factors enter which show a gain for the Diesel electric over the direct-connected Diesel. At least, there is little choice from the fuel cost standpoint, as the additional weight of the direct-connected Diesel over the Diesel electric drive causes the net returns to be practically

*Diesel engines or the equivalent.

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the same. As a matter of fact, the additional cargo that can be carried by a Diesel electric ship shows to a considerable advantage over short trips. The net fuel consumptions of the two drives are brought still closer for the reason that the direct-connected electric motor can be easily arranged for a lower and more efficient propeller speed than is usually the case with the direct-connected engine. There is a tendency to speed the direct-connected engines up in order to decrease weight per shaft horse power, resulting in lower propeller efficiencies.

The ordinary internal combustion engine using gears will probably see very little more development under present conditions.

The internal combustion engine or Diesel electric drive using direct-connected motors offers possibilities superior to those of any other type of drive, as will be shown in detail later.

For convenience, ship drives may be classified as follows, according to capacity of the propelling equipment: (1) Ships up to and including 6000 h. p.; and (2) Ships in excess of 6000 h. p.

For drives up to and including 6000 h. p., we might logically have reciprocating engine, geared turbine, turbine electric, direct-connected Diesel, and Diesel electric types of propulsion.

For drives in excess of 6000 h. p. we might have geared turbines and turbine electric. At the present writing, it is believed that the development of the Diesel engine in direct-connected units in excess of 3000 h. p. is not perfected. Neither has the development of the high-speed Diesel units for electric drive been perfected in sizes which will permit a drive in excess of approximately 6000 h. p.

Unquestionably, the prime consideration is reliability, while economy, simplicity, cost weight and space are important but secondary considerations. One must not be unmindful of the fact that when a ship leaves port, it must absolutely rely on its propelling equipment to reach its destination, and therefore, the lives of crew and passengers as well as the safe transport of the ship and its cargo are dependent upon the satisfactory performance of the propelling machinery. For this reason, reliability should not be sacrificed for any other consideration. Reliability necessitates close adherence to rugged and thoroughly proved apparatus which must, of necessity, stand more or less abuse without danger of failure. The machinery must operate continuously for days and possibly for months without shutting down, and must be simple within reason and thoroughly understood by the operators. Economy, cost, weight space, etc., are important in that they determine the relative earning capacity of the ship.

Merchant Shifs

With these general statements in mind, let us consider more closely the merits of electric drive, first for merchant ships, and second for battleships. As stated above, there are two general systems of electric propulsion, namely that in which the prime mover is the steam turbine and that in which the prime mover is the Diesel engine. With the turbine electric drive, the electrical equipment is of the a-c. type for the reason that a-c. turbo-generators are inherently better suited for the high economical speeds of turbines. With the Diesel electric drive, the electrical equipment is of the d-c. type, because of its flexibility, ease of speed control and simple requirements of the engine governors. If alternating current were used with Diesel electric drive, the engine governors would have to be highly refined as it would be necessary to operate the generators in parallel; whereas with direct current, the generators may be operated in series, thus permitting relatively simple engine governors. Even with parallel operation of the d-c. generators, the governor problem offers no serious difficulty, however, there are other decided advantages in favor of the series operation which will be discussed later. In the case of the turbine electric drive, the propeller speed is varied by throttling the turbine, and reversal of propellers is effected by reversing the motors connections. In the case of the Diesel electric drives, the propeller speed is varied any amount from zero to a maximum in either direction, without opening a single circuit, by merely adjusting the generator voltage by means of a simple field rheostat, the engines always operating at constant speed.

In the turbine electric drive, the motors are direct-connected to the propellers. As most ships up to 6000 h. p. are of the single-screw type, there is usually but one turbo generator and one motor. The electrical characteristics are usually 50 to 60 cycles, 1100 to 2200 volts, and polyphase. The control of the apparatus is effected from a central control station usually located in the engine room. The switches and turbine control valves are controlled by means of simple levers, symmetrically arranged and suitably interlocked in order to prevent improper operation. All necessary gages and electrical instruments are mounted upon a panel directly in front of the operator, so that the performance of the machinery is under his observation at all times.

The turbine is equipped with a speed governor, over-speed stop governor and throttle valve. Where the throttle valve is not used to regulate the speed, some form of "power limit stop" is necessary to prevent excessive overloads being imposed on the machinery when maneuvering or by other causes

In the case of twin-screw ships having two generating units, turbine electric drive possesses the advantage of flexibility over direct-connected and geared drives, in that the failure of either generating unit will not seriously cripple the propelling equipment. Should one unit fail, the remaining unit would deliver equal power to both propellers to the extent of its full equivalent capacity, thus enabling the ship to make about 70 to 75 per cent of full speed. This is also true to a large extent in the case of the geared turbine drive using cross compound turbines, as the failure of a high

or low-pressure turbine element would mean the loss of only from 40 to 50 per cent of the power. In the case, however, of complete expansion turbines, the failure of one unit would necessitate dragging that screw, resulting in a serious retarding effect. Large ships invariably have twin, tripple or four screws, and therefore, the flexibility of the electric drive is an important advantage.

For ships up to 6000 h. p., (the larger sizes having twin screws) the Diesel electric type of propulsion possesses marked advantages over all other types. With this type of drive, any reasonable number of generating units may be used, independent of the arrangement of the propellers. It is, therefore, possible to use a number of relatively small reliable, high-speed Diesel engines driving direct-connected d-c. generators[1]. By using a number of the small units, the disadvantages of large Diesel engines are obviated. Aside from the reliability thus obtained, there is the added important advantage of flexibility with regard to reserve power, and as will be shown later, this advantage is possessed in an extreme degree only by the Diesel electric drive.

The electrical apparatus is well understood, thoroughly tried out, and there is consequently no question as to its reliability. The motors are separately excited at constant potential in one direction while the generators are supplied with excitation through a reversing field rheostat so that any desired voltage may be obtained from zero to the maximum in either direction. With this arrangement, the speed of the motors is directly proportional to the voltage of the generators. Therefore, the control is as simple as could possibly be desired.

Series connection of the generators with the motors interposed to reduce the ground voltage to a minimum has certain advantages over parallel connection of generators. For the purpose of discussion, let us assume a single-screw drive consisting of six generators and a motor consisting of two separate units mounted on the same shaft. Electrically, the machines would be arranged in series as follows: Three generators, one motor unit, three generators, one motor unit. On the basis of 250-volt generators, the maximum ground voltage would be 750 volts, although from the standpoint of current, the system has all the advantages of a 1500-volt circuit. This arrangement of generators and motors is independent of the number of either. Even with an uneven number of generators in series, the motor may be on different screws as in the case of a twin-screw drive, and still permit independent control of the port and starboard screws. However, with the same or opposite rotation of the screws, the amount of speed difference obtainable is somewhat limited, although wholly within requirements. In this case, the speed difference between the propellers is obtained by adjusting the motor fields. An even number of generators is preferable with twin-screw ships, however, as it affords more flexible and more positive control.

The advantages of the series system over the parallel system from an engine operating standpoint has already been covered.

With the series arrangement, more power can be obtained from remaining generator units in case of failure of one or more generator units, without providing excess capacity in the motors. The reason for this is that each of the remaining generators can be operated at normal voltage and the field of the motors weakened to increase the propeller speed to a value which will load the remaining generator units to their full capacity. With parallel operation, it would be necessary to lower the voltage of each generator a certain amount, thereby operating them at reduced capacity; or else to operate the remaining generators at full voltage and provide additional field capacity in the motors so that the speed could be lowered the required amount by increasing the motor field. Thus, in case of failure of a generator unit, parallel operation would either afford slightly less power than series operation or would necessitate slightly larger and heavier motors.

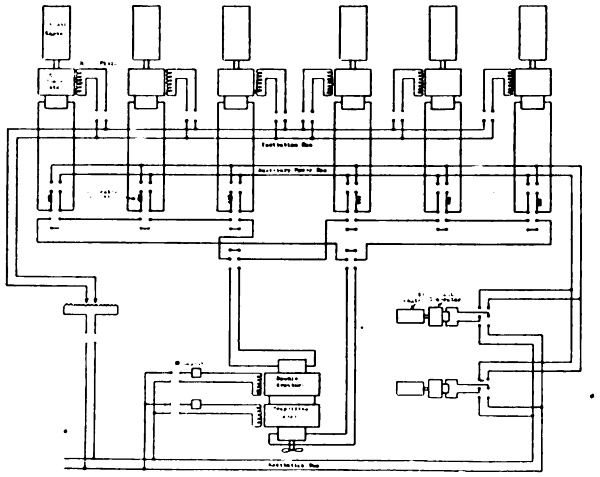

Fig. 1—Diesel Electric Drive, Schematic Arrangement Electrical Connections

The Diesel electric system of ship propulsion possesses a flexibility of reserve power in the case of failure of prime movers which far surpasses any other type of drive. For example, assume a case in which there are three generators and one motor. Should one of the engines fail, the remaining two units could be operated at full capacity, giving two-thirds the total voltage and the motor speed increased by weakening its field to a point where the propeller would require two-thirds of full power, with a resulting ship speed of approximately 88 per cent. In the case of two engines failing, the available speed of the ship would be ap-

1. It is not the intent of this paper to discuss Diesel engines, and it is assumed that it is generally recognized that Diesel engines having relatively small cylinders and operating at reasonably high speeds are thoroughly reliable and simple.

proximately 70 per cent of full speed. And to assume the remote case of all main engines failing, the ship could make steerage way on the auxiliary generating sets.

The multiplicity of units of the Diesel electric system affords another advantage of great importance, namely, that units can be overhauled at sea without entailing any serious loss of speed.

In the way of a summary, the following table of comparison of the various principal drives will be of interest. In arriving at the figures given, all items of machinery and supplies necessary to the main propelling machinery were considered; foundations, water, fuel, etc., were taken into account. However, it was necessary in some cases to make certain assumptions, but an effort was made to place such assumptions on the conservative side, so as not to show an exaggerated comparison. Further, certain major figures are at great variance in practise, and the table is, therefore, given as indicative of the trend of this comparison rather than actual proportions. The figures for turbine electric drive and geared turbine drive are based on the same steam conditions.

The figures are based on a 3000 h. p. ship operating over a 4000 mile course at a speed of 11 knots, and making a total of 14 single trips per year. The geared turbine ship is taken as unity. Owing to the present unsettled conditions, it is hardly possible to make an intelligent cost comparison.

Drive	Fuel Consumption	Machinery Weight
Geared turbine	1	1
Turbine electric	1.06	1.05 to 1.10
Direct-connected Diesel	0.49	1.10 to 1.25
Diesel electric[2]	0.57	0.75

Battleships

The requirements of propelling machinery for battleships differ from those for merchant ships, principally in the degree of reliability and maneuvering ability. The reliability factor is of considerably greater importance, and must be made secondary to no other consideration. The maneuvering ability of a battleship is of great importance because of the range of speed at which it operates, and the promptness and accuracy with which it must respond to signals. Certain refinements are necessary for battleships which are not advisable for merchant ships, but because of the continually changing personnel of the former, these should always be kept within reasonable simplicity.

It is not the intent of this paper to compare various types of drives for battleships, and therefore only a few brief remarks will be made in this connection. The advantages of electric drive for battleships, or warships, lie particularly in the flexibility of the arrangement of the machinery with respect to its protection from torpedo attack. Secondary advantages lie in the availability of full backing power and flexibility of control. Flexibility of control is important, both from the standpoint of normal operation, and also emergency operation, as in case of a failure of one of the main prime movers. Within reason, the machinery can be placed where it is best protected from torpedo attack. The total floor area occupied by the propelling machinery and its weight might be slightly in excess of a well designed geared turbine drive. However, if the geared turbine drive is arranged to be equally well protected from attack, it is possible that the slight advantages of these two factors would be of very minor consideration. Unfortunately, there are no comparable geared turbine drives in operation, or under construction, to enable a close comparison of these factors to be made. Similarly, there are no directly comparable ships having geared turbine propelling machinery to enable a comparison to be made of the economy. (In this connection, sister ships of the *New Mexico* having direct-connected main turbines and geared cruising turbines have shown decidedly poorer economy under all conditions than the *New Mexico*).

It is safe to say, however, that the difference in economy, if any, would be very little. The geared turbine drive might show a slightly better economy at full power, whereas the electric would be expected to show better economy at the lower powers and cruising speeds, providing equal efforts are made toward economy by design and operation. In the case of the geared drive, it would be necessary to use all turbines (except where cruising turbines are provided) for any speed, whereas with the electric drive only a sufficient number of generators are operated to supply the power required for a given speed. This enables the generating equipments of the electric drive to be operated at full power nearly all the time. Furthermore, since the motors have two sets of windings, or the equivalent, the generators and turbines can be operated at higher average speeds over the entire range, resulting in better economy.

There can be no question as to the reliability of electrical apparatus as the propulsive power for ships of this class. Electrical machinery has been developed over a long period of years and has proven extremely reliable in all sizes, and the experience with this class of apparatus will support the statement that it is as reliable as any other class of machinery that can be installed on ships.

The experience of the engineer officers who have had charge of an electrically driven battleship, and also of battleships having other types of machinery is that the electrically driven ship is more easily controlled, and affords quicker response to signals than any other of type drive. The equipment can be made in such a manner that the entire propelling equipment is under

2. There is a farther decrease in fuel consumption with Diesel electric drive which has not been taken into account in this comparison, namely that due to lower propeller speeds obtainable with low-speed motors.

the control of one operator. In fact, such an arrangement will be used with the new battleships and battle cruisers. In this case, the control will be almost entirely electro-pneumatic, and the main operating board will resemble the control boards used in the large railway switch towers. Any desired rapidity of operation within reason can be otained with the electrical equipment. For instance, upon receipt of a signal to go full speed astern from full speed ahead, the propellers can be made to turn over in the reverse direction inside of a period of approximately ten seconds.

Also the facility with which electrical energy can be measured and indicated, enables the instantaneous conditions of the propulsive equipment to be observed at any time, and therefore enable the operating force to detect excessive shaft friction, damaged screws or other abnormal operation. The electrical instruments are also beneficial in operating the machinery at its maximum economy at all times.

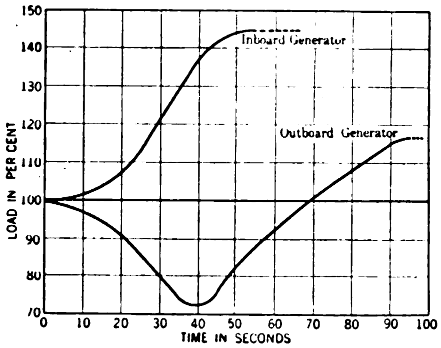

FIG. 2—TURNING WITH 35-DEG. RUDDER (POWER LIMIT NOT SET)

Starting and running requirements under normal sea conditions are not severe. If, however, precautions are not taken to limit the power, it is possible to impose large overloads on the machinery when turning a ship or reversing. The accompanying curve shows the manner in which the power of the inboard and outboard sides varies when making a turn with 35 deg. rudder. The particular curve shown has been interpolated from the curve obtained on the battleship *New Mexico* when making 19 knots and turning with 35 deg. rudder. It will be noted that the power of the generator supplying the inboard side increases rapidly during the first 50 sec., at which point it reaches the maximum output of the turbine. On the other hand, the power delivered by the generator supplying the outboard side decreases rather rapidly during the first 40 sec., and then begins to increase rapidly until a constant value is reached at about 90 sec. An analysis of the curve shows that the inboard side developed an overload of approximately 45 per cent when the maximum power of the turbine was reached. The outboard side dropped to about 75 per cent of normal load at the end of the first 40 sec., and then increased to a value corresponding to approximately 15 per cent overload at the end of 90 seconds. The total power at the end of 90 sec. corresponds to approximately 130 per cent load.

If such conditions as those mentioned above are not guarded against, it would be necessary to carry excessive excitation on the generators continuously as the equipment would have to be ready at all times to meet the requirement. This would result in considerably larger generators. However, to overcome this condition, a form of power-limit stop is provided, the function of which is to limit the amount of steam taken by the turbine to a predetermined value, which under normal operating conditions corresponds to an overload of about 10 per cent. The shape of the turning curves and the overloads obtained varies with the different ships, and it is therefore necessary to conduct a series of "drop out" tests on each ship in order to determine the field current that must be carried continuously at the different speeds to enable the ship to be maneuvered without liability of the motors and generators pulling apart.

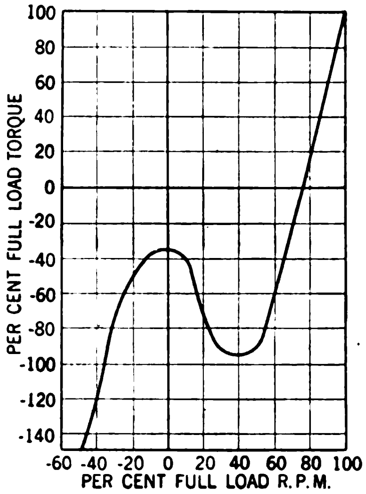

FIG. 3—PROPELLER TORQUE CHARACTERISTICS—REVERSING
Ship going ahead at constant speed.

Fig. 3 shows the conditions which exist when reversing a battleship at full speed. The relative proportions of this curve also depend upon the ship in question, but the curve shown can be considered more or less typical as showing the backing conditions. In order to show the motor torque available for taking care of the backing condition, a series of motor speed-torque curves have been plotted in Fig. 4. The motor in question is of the wound-rotor type, having adjustable external resistance. A few speed-torque curves have been drawn for different secondary resistance values, but with liquid rheostats, there would be an infinite number of such curves as the external resistance thus provided varies from a maximum to the short-circuited condition of the rotor. With this type of rheostat, it is possible to obtain the maximum torque at any instant. An inspection of the ship torque curve will

show that the speed of the propellers drops to approximately 75 per cent when the power is taken off. This portion of the curve is represented by the straight line to the right. At this point, the motor connections are reversed and the motors produce a torque opposing the turning effort produced by the motion of the ship on the propellers. This reverse motor torque then builds up to approximately full-load value at 40 per cent ahead revolutions, and then decreases to approximately 35 per cent when the propellers are brought to a standstill. When the speed of the propellers is increased from zero rev. per min. to values as low as 40 per cent full-load rev. per min. in the backing direction, the torque increases very rapidly, attaining at this point a value slightly in excess of 100 per cent which is the maximum speed that can be obtained without exceeding full-load tor-

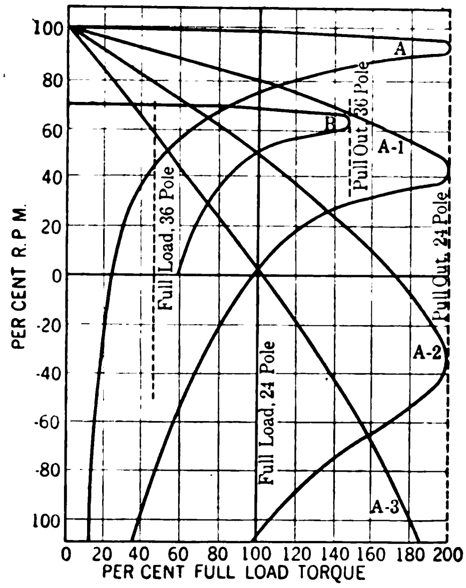

FIG. 4—U. S. S. TENNESSEE MOTOR SPEED-TORQUE CHARACTERISTICS

A—24-pole (wound secondary)
A₁, A₂, A₃.—24-pole winding with external resistance
B— 36-pole (squirrel-cage winding)

que of the motor. This curve, however, is plotted on the basis of the ship maintaining its full lineal speed through the water. Under actual conditions, however, the ship will slow down considerably in the time taken to reach this point, and it will therefore be possible to obtain a higher rotational speed of the propellers in the backing direction than this curve indicates.

The most vital part of the curve is that at about 40 per cent of full-load speed when bringing the propellers to a stop condition. In the case of wound-rotor motors, this condition presents no difficulty as it is possible to obtain torques considerably in excess of normal at any speed by simply adjusting the external resistance. In the case of squirrel-cage motors, however, it is necessary to introduce a special design so as to obtain a speed-torque curve which will enable the motor to deliver torque safely in excess of this requirement, and under the conditions of operation described.

Further details of backing and turning conditions can be obtained from articles by Commander S. M. Robinson, U. S. N. published in the *Journal* of the American Society of Naval Engineers, from which data for the above curves have been taken. All such conditions must, of course, be taken into strict account in designing the propelling equipment and it is obvious that the turbines, generators, motors, and control must be designed as a unit in order that each will have characteristics which are sufficient to enable all parts of the equipment to function properly under the required conditions.

Description of Apparatus. The propelling machinery of the *U. S. S. Tennessee* consists of four direct-connected, 2-speed motors supplied with 3-phase power through suitable control equipment at approximately 3400 volts and 34.6 cycles (full speed) by two direct-driven, 2075 rev. per min. turbo generators. The generators are excited from one of the 300-kw., d-c. auxiliary sets through a booster set, so designed as to vary the 240-volt bus voltage in either direction to a value best suited for the given condition. All engine room auxiliaries necessary to the main propulsion such as the main and auxiliary condenser circulating and condensate pumps, the lubricating and governor oil pumps, the oil cooler circulating pump, and the main motor ventilating blowers are driven by d-c. motors supplied with power from the same generator which is used for supplying the excitation. One auxiliary generator in each engine room is sufficient to supply the auxiliary load just mentioned.

From the maximum speed to a speed slightly in excess of 16 knots, two generators are used, and the motors are connected to the 24-pole winding; speeds below this are obtained with only one generator in use. Speeds up to and including 15 knots can be obtained with the motors connected to the 36-pole winding.

The steam operating conditions are 280 lb. gage at the boilers, 250 lb. gage at the turbine throttle, and a vacuum of 28.5 in. of mercury referred to 30 in. barometer.

Main Motors. The main propelling motors are of the induction type and are wound for two definite speeds at full frequency, there being a 24-pole and a 36-pole winding. The primary or stator has two independent windings, one for each set of poles. One set of slots accommodates both of these windings, there being two coil sides of each set of coils placed in the slot, one directly above the other.

The rotor has a three-phase, two-parallel star-connected winding, having balancer connections operating as such on the 24-pole winding. The 24-pole winding is connected to three slip rings. The balancer connections are connected to points of equal potential in such a manner as to form short-circuit paths for the rotor conductors when the stator is connected to the 36-pole winding, thus forming an ordinary squirrel-cage winding having straps connecting the

rotor conductors together instead of resistance rings.

In general, the design of the motors follows standard land practise. There are, however, certain features, particularly in connection with the insulation of the windings that have been given special consideration to guard against the deleterious effect of salt and moisture conditions. The insulation is of the best known material and is applied and treated in accordance with thoroughly tried methods. The coils are form wound, and completely insulated before being placed in the slots. The insulation of the straight part of the coil which is imbedded in the slot consists principally of mica with just sufficient fibrous material to serve as a binder. The mica folium and mica plate constituting this insulation are applied loosely by hand, and the coil then placed in a special machine equipped with electrically heated bars which revolve under spring pressure around the wrapper. This process softens the bond, and permits the wrapper to

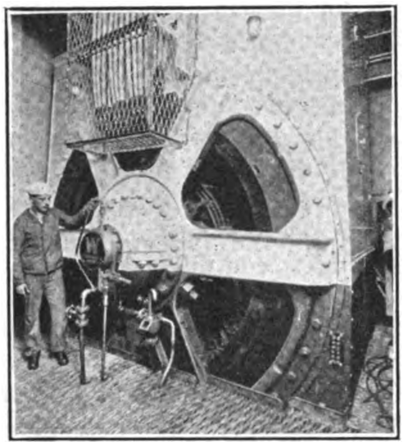

Fig. 5—Starboard Outboard Motor

slide on itself, resulting in an extremely solid and compact insulation. After the ironing process is completed, the coils are placed in cold presses and pressed to the required dimensions. The ends of the coils where flexibility is required are insulated principally with specially treated fibrous material. Whereever cotton tape or other material subject to deterioration at relatively low temperatures is used, it is for convenience of assembly only, and in no case are the insulating or mechanical qualities depended upon where there is a danger of the neighboring iron or copper reaching a temperature questionable for class A insulation. The tape constituting the insulation for the ends of the coils is given several treatments of insulating varnish during the process of winding. This tape is joined to the insulation of the straight part of the coil with specially prepared cement. The outside coverings are thoroughly filled with insulating varnish by means of several successive treatments; each coating being baked on for a long period, resulting in an insulation having a coating which is impervious to moisture and capable of withstanding salt deposits and foreign particles of dirt, etc., which may eventually find their way into the motor.

The slots are lined with tough paraffined fish paper cells in order to protect the insulation of the coil from injury during the assembling operations. This cell laps over the top coil, forming a protection of the coil from injury by the micarta wedges which are driven in the teeth of the slots. The individually formed coils are separated from each other by micarta spacers and any additional space in the slot is filled with micarta plate so that there will be no room for coil movement.

The connectors joining the coil ends are insulated with thoroughly treated fibrous tape.

The bottom layer of stator coils is securely laced to a strong insulated steel supporting ring which, in turn, is supported to the frame by means of bolted brackets. Another insulated steel ring support is placed between the two windings of the stator and held in place by means of copper wires which extend around the ring and the individual coil ends of both stator windings. With this type of construction, all coil extensions are grouped into a single mass which is rigidly supported from the motor frame, thus preventing coil distortion from any cause whatsoever.

The rotor coil extensions rest firmly upon a wide insulated support, to which they are secured by heavy insulated bands.

The mechanical construction of the motor is of the self-contained type in which the bearings are carried by suitable brackets which fit into recesses in the stator frame. The entire motor is supported by feet cast integral with the frame on either side. The bearing housings are readily adjustable radially by means of jack screws in the brackets, and after being adjusted, are bolted rigidly to the bracket.

The ventilation is supplied by duplicate d-c. motor-driven exhaust blowers, each capable of 12,500 cu. ft. per min. maximum. In addition to these separate blowers, the rotor itself is provided with fan vanes which assist in the ventilation and which will supply sufficient air to enable the motors to be operated for brief periods at full load in case of failure of the separate blowers. The separate blowers are mounted on the top of the motors, and draw the air through the motor and discharge it through suitable ducts to the deck. The system of ventilation consists of the axial flow of air through the core and end windings, the air being drawn in through openings in the brackets and discharged through a radial duct at the middle of the core to an outlet at the top of the motor.

Each motor is capable of delivering a maximum of 8375 h. p. at a speed of about 185 rev. per min.

The stator is provided with six thermocouples which are used in connection with potentiometers mounted in the control room for measuring the hot-spot temperatures of the windings. This device

gives actual measurement of the actual hot-spot temperature and readings taken therefrom need no further correction except the 5 deg. for insulation drop.

In order to maintain the temperature of the motors above that of the surrounding air when the motors are idle, d-c. heaters are provided. These heaters consist of a series of tube resistors secured to the motor frame and so arranged as not to cause any excessive local heating.

Main Generators. The main generators are designed and constructed in accordance with standard land practise, except that the rotor is of the totally enclosed type. The stator coils are insulated in substantially the same manner as described for the motor coils. Each generator is capable of delivering a maximum of about 15,000 kv-a. at approximately 36½ cycles.

The air pressure for ventilation is supplied by means of blowers secured to each end of the rotor. The air is drawn from a duct below the generator through the end bells, entering the machine at each end of the rotor. From there, it is forced through the end windings,

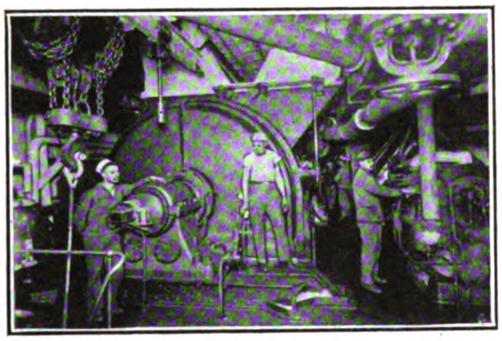

FIG. 6—MAIN TURBO GENERATOR, FORWARD ENGINE ROOM

core, and air gap axially, and discharged radially through a central opening in the core and passes from thence through a duct to the deck.

The rotor consists of a solid steel forging having radial slots for receiving the windings. The winding consists of a series of turns of bare copper strap, the insulation of which consists entirely of mica and asbestos.

Similar to the motor, the generator is provided with thermocouples for measuring the hot-spot temperatures. These thermocouples also connect to the same potentiometer board in the control room.

In order to prevent the generator from sweating when idle, steam heating coils are provided. These coils are so located as not to cause any excessive local heating and all joints and connections to the pipe are made outside of the frame of the machine so as to avoid steam leaks into the machine.

Turbines. The turbine is of the combined impulse and reaction type, allowing complete expansion of the steam in one cylinder. Steam from the throttle valve and governor valve is admitted to openings in the top and bottom at the center of the turbine through control valves in the connections to these openings, and thence into various nozzle groups. The steam expands in the nozzle and passed through a set of impulse blades and thence through single-flow, high-pressure reaction blading; having passed through this high-pressure reaction blading, the steam divides, one-half continues through the low-pressure blading on the same end of the turbine, and the other half flows through an overhead connecting pipe to the low-pressure reaction blading on the other end of the turbine. An exhaust connection is provided at each end of the turbine.

The number of hand nozzle control valves to be opened at one time depends upon the load and varies from one to three valves.

The speed, of course, is regulated by the governor valve only, the use of the hand valves being merely to obtain the best economy and to prevent overloading of the boilers at the various standard speeds.

The turbine is coupled to the generator by means of a pin-type flexible coupling.

The glands for preventing leakage along the rotor shaft are of the combined steam and water sealed type. The water gland is designed to effectively seal at all speeds from and above half speed. Below half speed, the steam seal gland is used. The steam pressure is regulated by a reducing valve in the pipe line to the glands. The water for sealing is supplied by a small connection from the feed line. The water and steam for gland sealing is controlled by special automatic gland control valves.

Briefly, the principal speed-control system consists of a governor driven directly from the turbine shaft through suitable gearing. The governor which is capable of holding a practically constant speed at any speed from about 25 per cent to the maximum, is essentially a dead weight governor in which the dead weight is replaced by a hydraulic piston, resulting in a type of governor capable of functioning over a wide range of speed by varying the hydraulic pressure on the piston. The speed is adjusted hydraulically by means of a control valve in the main control room which regulates the oil pressure. A double-seated poppet valve located on the main steam inlet to the turbine is controlled through a floating lever oil pressure relay system from the main governor, and this valve controls the amount of steam required to maintain the speed for which the system is set. The governor control valve is also operated through a suitable oil pressure relay by a separate over-speed governor secured to the end of the turbine shaft. In addition, this overspeed governor also operates the main throttle valve in case of necessity.

In order to limit the power input to the turbine on overload conditions to an amount which will prevent excessive overloads on the machinery, and also prevent priming of the boilers, a power-limit stop is provided. This power-limit stop is arranged to limit the travel of the governor linkage in the direction which

admits more steam, as mentioned above. The position of the stop is adjusted electrically from the main control room through a system of gearing operated by a small motor. In order that the operator may know the position of the power-limit stop at any instant, an electrical position indicating system is provided, the transmitter of which is driven by spur gearing from the power limit stop mechanism. The indicator is mounted on the main control board in the control room under the direct observation of the operator.

In operation, this system function as follows: The speed of the ship is set from the control room for any given standard by means of the hydraulic speed-control system. The power-limit stop is then adjusted to limit the motor speed to a few revolutions above that corresponding to the standard speed. Should an overload occur from turning or from any other cause, the speed-control governor will tend to maintain a constant speed by admitting more steam. However, as the governor linkage has only an additional limit of travel corresponding to the few revolutions increase in motor speed, the steam which can be admitted to the turbine is therefore limited, and consequently the overload has a fixed value for any given condition.

The power-limit stop may also be used for adjusting the speed of the turbine below any value for which the main speed governor system is set, and it accomplishes this in a similar manner to throttling.

Since the speed is a function of the oil pressure, oil gauges mounted in the control room give a further check on the proper functioning of the entire turbine control system.

The over-speed stop may be operated direct from the over-speed governor, hand trip in the engine room, or by wire pull from the control room.

The turbine and generator bearings are lubricated by means of forced lubrication through a system of delivery and return pipes. Oil for the governor control system is also supplied from the same system. The oil is delivered to the governor system at 80 lb. pressure and to the bearings at 5 to 10 lb. pressure through a reducing valve or other suitable means. The oil pumps for circulating this oil are of the positive displacement rotary type. Two pumps are provided in each engine room, one of which is motor driven and the other turbine driven, the turbine-driven pump standing by as a spare. Normally, the motor-driven pump is used. However, upon failure of the motor-driven pump from any cause, an arrangement of pistons operated by the oil pressure will automatically cause the turbine-driven pump to be placed in operation.

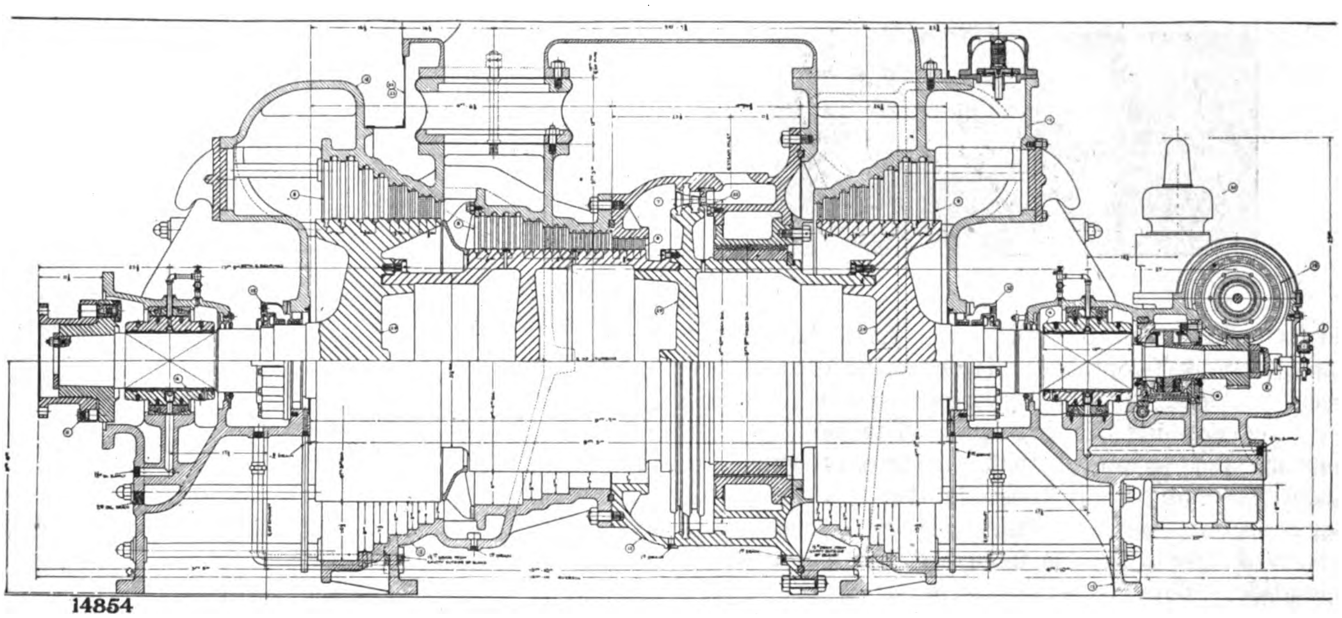
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FIG. 7—CROSS-SECTION TURBINE U. S. S. TENNESSEE.

Main Control. As in the case of any other drive, the control for the electric drive such as is installed on the *Tennessee* is operated under orders from the bridge. All controlling apparatus necessary for the operation of the main propelling machinery is located at a central place known as the control room, and the operating levers are arranged so that the operator faces forward. All operations for the control of the ship are effected in this control room except the actual starting of the turbines. The circuit breakers for handling the main circuits of the propelling machinery are of the oil break type, of sufficient capacity to safely open the circuits under full power and voltage conditions, although in normal operation the circuit breakers are never opened or closed while the circuits are alive, suitable interlocks being provided to guard against improper operation. All primary breakers are arranged in two rows athwart ship having an aisle

between them through which the breakers may be inspected and removed, if necessary. Secondary short-circuiting breakers and the liquid rheostats for controlling the motor secondaries are located back of the operating aisle.

The circuit breakers are designed with special reference to ease of operating, having wedge-shaped contacts of the multiple finger type. The circuit breakers are operated in pairs from single-control

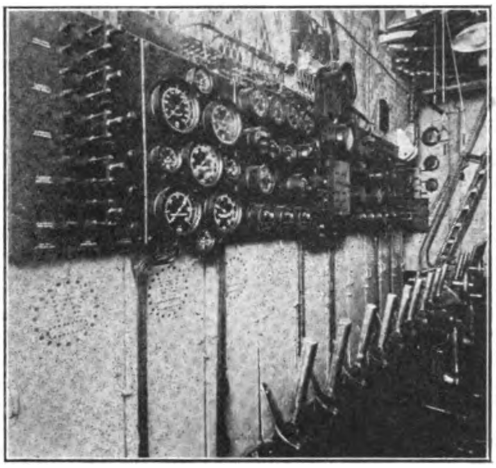

FIG. 8

levers. In order to kill any particular circuit completely, self-contained disconnecting devices have been provided on the reverser breakers, generator breakers and tie breakers. The breaker mechanism is so arranged that the breaker must be opened before it is possible to disengage the disconnecting device. This provision safe-guards against danger to the men in case of improper or faulty operation. The inspection or repair of the circuit breaker or circuits of any one or two motors at a time is thus facilitated, and can be executed while the ship is under way.

The levers for operating the circuit breakers and the liquid rheostat valves are arranged in a single row directly aft of the circuit breaker structure. All instruments and gages for indicating the performance of the machinery are located on control panels secured to the circuit breaker structure directly in front of the operators. The levers are arranged symmetrically so that those on the left of the central position operate the circuit breakers in the after generator and port motor circuits, while those on the right of the central position operate the circuit breakers which control the circuits of the forward generator and starboard motors.

The connecting rods and bell cranks between the levers and the circuit breaker mechanism are located beneath the false floor which forms the operating platform.

The pedestals on which the turbine control valves mentioned above are located, and also the levers for operating the generator field switches are located in the center of the lever group. Suitable mechanical interlocks of the crotch and rod types are provided so as to prevent improper operation of the switch levers. All interlocking is so arranged that the field must be off and the steam control reduced to a low value before any of the operating or set up breakers can be operated. This interlocking also necessitates proper sequence of operation in either starting or stopping, the broad purpose of which is to safe-guard the machinery.

The arrangement of the control is such that either side of the ship can be operated independently of the other side when two generators are in use. With the tie breakers closed and either generator in operation, the port and starboard propellers may be operated in the same or opposite directions as desired, but at the same speed.

All starting and maneuvering are done on the 24-pole winding.

When the motors are connected on the 24-pole winding, the secondaries are controlled by means of

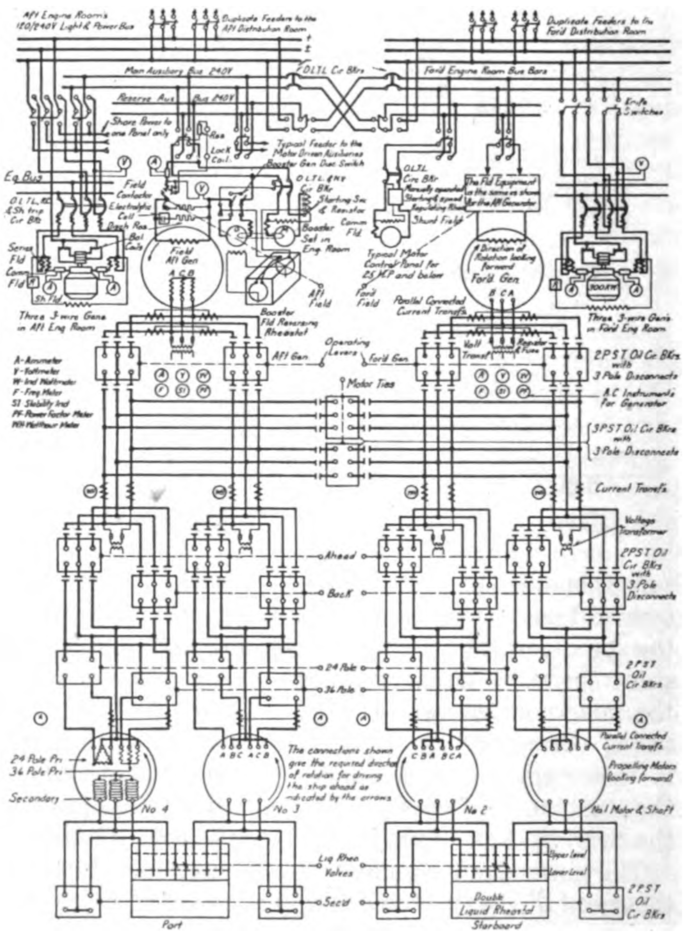

FIG. 9—DIAGRAM OF CONNECTIONS OF THE MAIN A-C. AND D-C. CIRCUITS FOR THE PROPELLING MACHINERY OF THE U. S. S. TENNESSEE

liquid rheostats. There is one double rheostat for port motors and one for starboard motors. The rheostat consists essentially of a 2-compartment tank, the lower compartment of which serves as a reservoir for the electrolyte and also as a container for the

cooling coils, while the upper compartment contains the electrodes which are of the plate type. When it is desired to use a rheostat, the valve in the upper compartment operated from the control stand by means of a lever, is closed, thus allowing the liquid to rise in the upper compartment. (The liquid is being continually circulated through the upper compartment at a low level by means of motor-driven pumps.) The rate at which the liquid rises depends upon the setting of the regulating valve located in the delivery

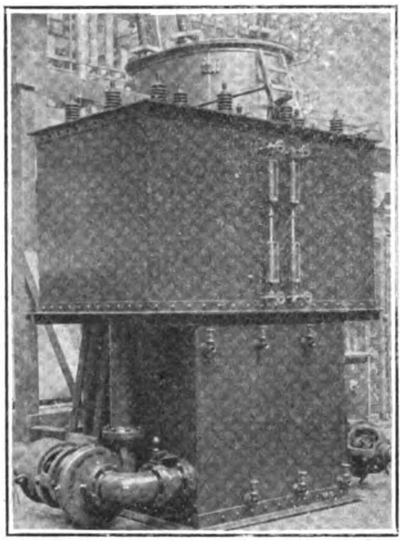

Fig. 10

pipe of the pump. This valve can be adjusted to suit the desired operating condition. After the liquid rises to its maximum level, it overflows to the bottom compartment. After the maximum level has been reached, the motor secondary is completely short-circuited by means of an oil circuit breaker which is operated by a lever from the control stand. The electrolyte consists of a solution of ordinary sodium carbonate.

In order to transmit the power from the generators to the control room circuit breakers, and from there to the motors, three-conductor lead-covered cables are used, each cable containing all three phases, there being a sufficient number of these cables in parallel to take care of the total power. The cable ends are provided with pot heads forming water-tight seals from which the respective conductors are brought out and connected to very substantial and well insulated bus structures located over the switches in the control room, and at the motors and generators in the motor rooms and engine rooms respectively.

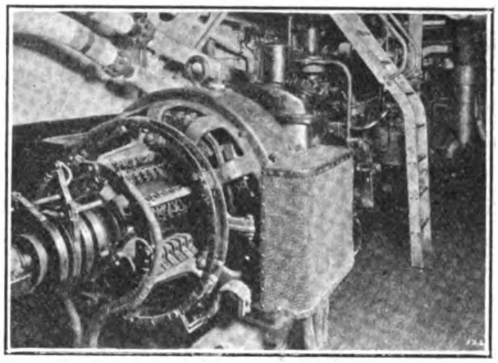

Fig. 11

The excitation for the main generators and power for the auxiliaries necessary to the propelling equipment is supplied from one of the 300-kw. sets in each engine room, as stated above. Connections of these circuits to the 300-kw. sets are made ahead of the carbon circuit breakers in order that an interruption by means of the circuit breakers will not shut power off the exciting circuits or the auxiliaries. The engine room auxiliaries and the motor ventilating blowers are provided with ordinary starting devices having individual circuit breaker protection.

STOCK OWNERSHIP IN PUBLIC UTILITIES

A new campaign for distributing its stock among the customers and employes of the Southern California Edison Company has been carried on for several months with unusually gratifying results. The advantage of consumer ownership in a public service utility has been generally recognized and the plan has met with notable success in the case of this company.

On June 24 the company completed the fifth month of its new stock-ownership campaign, at which time it had sold $7,985,000 par value of its common stock. This sets a record for the sale of utility stock to individual buyers. In 1917 when the company began offering its stock to its consumers it had a total of 1,864 stockholders. It now has 17,500 stockholders.

An interesting angle of consumer ownership is suggested by the following case: A man owning 20 acres under irrigation has a waterfall on the back of his property and it has an effective head capacity for generating 15 h. p., which would be about adequate for irrigation pumping on the average 20-acre ranch. His electric power bill, at rates fixed by the State Railroad Commission, is about $150.00 per year. If he were to undertake to harness his own cataract, it would cost him about $2,000 to install a small turbine and electric generator. The interest at 8 per cent would be $160 per year, the depreciation about 8 per cent per year, and the life of the machinery would not exceed 15 years. The purchase of twenty shares of stock would cost him $1,880, and yield him $160 per year, showing that he could get his power very much cheaper by being a partner owner in the utility than he could by developing his own waterfall.

On the Equivalence of the Two Theories of the Single Phase Induction Motor

BY V. KARAPETOFF

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It is shown that the two equivalent diagrams of a single-phase induction motor, viz., the one deduced from the revolving-field theory and that from the cross-flux theory, can be converted into each other. In other words, the two theories lead to the same performance of a motor with given design constants. It is also shown that many other equivalent diagrams are possible and that one of these contains a variable impedance depending upon the slip in one parallel branch only, the other parts of the circuit being constant.

THERE are two theories of the single-phase induction motor that are in general use among engineers, *viz.*:

1. *The rotating-field theory,* according to which the single-phase motor is replaced by two polyphase motors in torque opposition, with the stator windings in series and with separate rotors. This theory leads to the equivalent diagram shown in Fig. 1.

2. *The cross-field theory,* according to which there are two separate air-gap fields, one in space phase

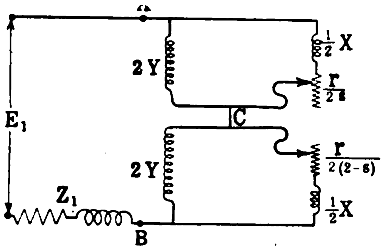

FIG. 1

and the other in space quadrature with the stator winding. This theory leads to the equivalent diagram shown in Fig. 2.

These two theories are considered in detail in E. Arnold's Wechselstromtechnik, Vol. V., Part 1, (1909) Chaps. 7 and 8, and the equivalent diagrams are proved there. Each theory leads to a circle diagram for the locus of the primary current, and on p. 15 Arnold shows that three points on the two circles coincide. From this fact he concludes with sufficient reason that the two theories lead to an identical performance for a given motor, and that if one of the two theories is correct, the other must be correct.

The process of finding the position of the center and the radius of the circle according to either theory is quite tedious, and the resulting graphical construction rather involved. On the other hand, the equivalent diagrams shown in Figs. 1 and 2 can be used analytically for the predetermination of performance or for any other investigation of the motor, without representing them graphically. It is of interest therefore to show directly the equivalence of the two diagrams of connections and to deduce a method of transforming one into the other.

In both figures, E_1 is the line voltage and Z_1 is the primary impedance consisting of the resistance of the primary winding and of its leakage reactance. Since Z_1 is taken into account in the same manner in both diagrams we are not further concerned with it in our comparison of the two diagrams. Y is the exciting admittance of the main magnetic circuit and is shown in the usual manner in Fig. 2. In Fig. 1 this admittance is shown separately as $2\,Y$ for each of the two component polyphase motors. Each fictitious component motor has only one-half as many turns as the actual motor and for this reason the exciting admittance has to be doubled (Arnold, ibid., p. 152.)

The meaning of the other symbols in the figures is as follows: $X = j\,x_2$ is the secondary leakage reactance and is used in the analytical part of this treatment as an operator in complex notation. The resistance r is that of the rotor, considering it as a single-phase circuit reduced to the primary number of turns. It is known from the general theory of the polyphase induction motor that in the equivalent electric diagram the load and the secondary resistance together are replaced by the resistance r/s, where s is the slip of the machine (see, for example, the author's "Electric Circuit," p. 123). One of the component machines in Fig. 1 runs at a slip s, the other at the slip $2-s$. Moreover, only one-half of the resistance of the actual

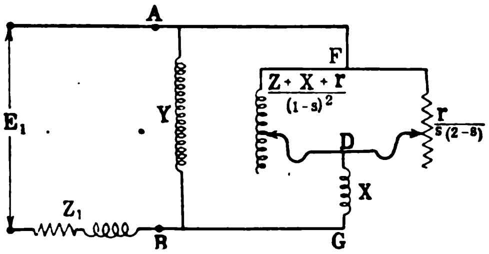

FIG. 2

single-phase machine must be assigned to each polyphase machine. This explains the meaning of the resistances $\frac{1}{2}\,\frac{r}{s}$ and $\frac{1}{2}\,\frac{r}{(2-s)}$. For the same reason $\frac{1}{2}\,X$ is assigned to each polyphase motor. The same quantities enter in Fig. 2 in a different form resulting from the crossfield theory. The impedance Z in this diagram is that of the main exciting circuit, so that $Z = \frac{1}{Y}$.

For the sake of abbreviation we shall also introduce the following notation:

$$Z' = \frac{1}{Y'} = \frac{1}{2}\,X + \frac{1}{2}\,\frac{r}{s} \tag{1}$$

$$Z'' = \frac{1}{Y''} = \frac{1}{2}\,X + \frac{1}{2}\,\frac{r}{(2-s)} \tag{2}$$

The total impedance between the points A and C in Fig. 1 is equal to $(2\,Y + Y')^{-1}$, and that between C and B is $(2\,Y + Y'')^{-1}$. Hence, the total equivalent impedance between the points A and B is

$$Z_{AB} = \frac{1}{2\,Y + Y'} + \frac{1}{2\,Y + Y''}$$

$$= \frac{4\,Y + Y' + Y''}{(2\,Y + Y')\,(2\,Y + Y'')} \qquad (3)$$

If the diagrams in Figs. 1 and 2 are equivalent, then equation (3) must also give the value of the total impedance between the points A and B in Fig. 2. To get the impedance between the points F and G, the admittance Y must be subtracted from Z_{AB}^{-1}. We then get

$$Y_{FG} = Y_{AB} - Y = Z_{AB}^{-1} - Y \qquad (4)$$

or, using the value of Z_{AB} from equation (3), we obtain, after reduction

$$Y_{FG} = \frac{Y\,Y' + Y\,Y'' + Y'\,Y''}{4\,Y + Y' + Y''} \qquad (5)$$

The corresponding impedance is

$$Z_{FG} = Y_{FG}^{-1} = \frac{4\,Y + Y' + Y''}{Y\,Y' + Y\,Y'' + Y'\,Y''} \qquad (6)$$

Multiplying the numerator and the denominator of this fraction by $Z\,Z'\,Z''$ and remembering that the Z's are the reciprocals of the corresponding Y's, we get

$$Z_{FG} = \frac{4\,Z'\,Z'' + Z\,Z'' + Z\,Z'}{Z'' + Z' + Z} \qquad (7)$$

In order to obtain the impedance between the points D and F, the reactance X has to be subtracted from the foregoing expression. We get then, after simple algebraic transformations,

$$Z_{FD} = Z_{FG} - X =$$
$$\frac{(2\,Z' - X)\,Z'' + (2\,Z'' - X)\,Z' + Z\,(Z' + Z'' - X)}{Z'' + Z' + Z} \qquad (8)$$

With the help of equations (1) and (2), this is directly reduced to

$$Z_{FD} = \frac{Z''\,r/s + Z'\,r/(2-s) + Z\,r/s\,(2-s)}{Z + X + r/s\,(2-s)}$$

$$= r\,\frac{Z + X + r}{(Z + X)\,s\,(2-s) + r} \qquad (9)$$

The total admittance between the points F and D is

$$Y_{FD} = Z_{FD}^{-1} = \frac{1}{r}\;\frac{(Z + X)\,s\,(2-s) + r}{Z + X + r} \qquad (10)$$

By adding and subtracting r in the parentheses of the first term of the numerator, this expression is transformed into

$$Y_{FD} = \frac{1}{r}\;\frac{(Z + X + r)\,s\,(2-s) + [r - r\,s\,(2-s)]}{Z + X + r}$$

or, writing the denominator separately under each term,

$$Y_{FD} = \frac{s\,(2-s)}{r} + \frac{(1-s)^2}{Z + X + r} \qquad (11)$$

Expression (11) represents two admittances in parallel and means that the circuit between F and D consists of the resistance $\dfrac{r}{s\,(2-s)}$ in parallel with the impedance $\dfrac{(Z + X + r)}{(1-s)^2}$. This conclusion agrees with the values shown in Fig. 2, which have been induced independently, from the cross-field theory. The equivalence of the two theories is thus proved.

Equation (10) is shown below to lead also to the equivalent diagram in Fig. 3. This diagram has the

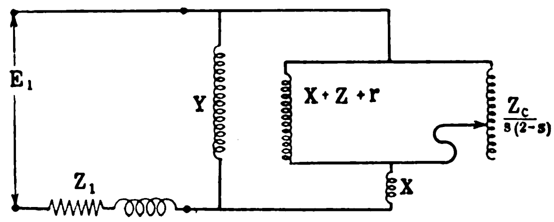

FIG. 3

advantage over Fig. 2 in that the impedance of one branch only is a function of s and varies with the load. As a matter of fact, the total admittance Y_{FD} may be resolved into two or more admittances in parallel or impedances in series in an infinite variety of ways, so that there is an infinitely great number of equivalent diagrams of the kind shown in Figs. 2 and 3. All of them are characterized by the shunted exciting admittance Y and by the series reactance X.

To prove that equation (10) leads to Fig. 3, we simply write the denominator separately under each term and thus obtain

$$Y_{FD} = \frac{(Z + X)\,s\,(2-s)}{r\,(Z + X + r)} + \frac{1}{Z + X + r} \qquad (12)$$

This shows that Y_{FD} consists of two impedances in parallel, namely $Z + X + r$, and $\dfrac{Z_c}{s\,(2-s)}$ where

$$Z_c = r\,\frac{Z + X + r}{Z + X} \qquad (13)$$

The fraction by which r is multiplied is a known complex quantity of the form $a + j\,b$, so that

$$Z_c = r\,a + j\,r\,b \qquad (14)$$

and this value is used in Fig. 3.

Neglecting the core loss, the impedance Z is a pure reactance, so that *approximately* we may put the foregoing ratio in the form

$$1 + \frac{r}{Z + X} = 1 - j\tan\phi \qquad (15)$$

where ϕ is a small known angle which is constant for a given motor and is determined by the constants r, Z, and X of the machine. Hence, approximately

$$Z_c = r - j\,r\tan\phi = \frac{r}{\cos\phi}\,\epsilon^{-j\phi} \qquad (16)$$

Two noteworthy papers on the single-phase induction motor, by Hellmund and by Lamme, as well as an extensive and stimulating discussion by others, will be found in the A. I. E. E. TRANS., Vol. 37 (1918), pp. 539-702.

SELF-CORROSION NOT STRAY CURRENT ELECTROLYSIS, SHOWN AT SELKIRK, MANITOBA

Evidence has been gradually forthcoming, from a number of independent investigators, that cast iron pipe is not the indestructible material that it was formerly supposed to be by engineers; and the recognition of the possibilities of self-corrosion by responsible engineers and chemists ought to have considerable bearing upon the numerous controversions respecting damage to water pipes, gas pipes, and lead cables, which is usually charged against stray current electrolysis from electric railways, if there is a railway near enough to receive the blame for the damage.

A perplexing feature that sometimes arises in an electrolysis situation, is the persistence of pipe corrosion, at spots well removed from the pipe joints, in areas where the pipes could not have been electrically positive to the surrounding earth. When the soil carries electrolytic salts in solution, self-corrosion is easily possible, in places where stray current electrolysis could not happen.

The facts that are now being brought to light about the possibilities of self-corrosion, coupled with the availability of recently devised methods for determining conclusively whether a pipe is positive or negative to the earth, will enable electrolysis situations to be handled in the future on a basis of proved fact instead of prejudice, fear or conjecture; and professional electrical engineers, called into electrolysis situations will do well to bear this in mind.

The following investigation of a case of chemical corrosion of iron pipe is reported by W. Nelson Smith, consulting electrical engineer of the Winnipeg Electric Railway Co.

A party of professional chemists and engineers from Winnipeg made a personal inspection of a six-inch water main, about 100 feet of which had been recently exposed in the course of excavating for the pipe tunnel between the new Selkirk hospital and the boiler house.

As the water supply system of the hospital is secured from wells drilled on the property to a depth of 250 to 300 feet, and the piping system is entirely separated from the Selkirk water supply, and as the hospital is more than half a mile from the western outskirts of the town, and not less than 1¼ miles from the northern extremity of the Selkirk trolley line, it was said to be quite outside any possible path of stray current from the electric railway. The only electric current on the property is a 60-cycle alternating current for lighting, and the United States Bureau of Standards, it was pointed out, had proved by exhaustive and long-continued experiment, that it was impossible for an electric current of this character to cause destructive electrolytic action on buried metal structures.

The pipes examined, although they had not been laid for more than eight years, were shown to be affected by some corrosion of the cast iron, well advanced in many spots, not only near the joints but in the middle of the pipe.

The progress of corrosion was observed in its various stages, and the corroded metal in the pits eaten into the pipes was similar in appearance to the products of corrosion observed on damaged water pipes in Winnipeg. All such damage, wherever it had happened in the city, it was stated, had always been attributed solely to electrolysis from stray currents leaking from the electric railway tracks.

The presence of soluble salt crystals in considerable quantity was also observed by all the party on clay freshly excavated from the new trenches in the street in front of the hospital. The similarity of this clay and its salt content, to the clay and its contained salts as met with all over Winnipeg and vicinity was remarked upon by all present.

This water pipe had thus been imbedded in earth containing salts that are known to be chemically active, and further, by reason of its location, had been entirely free from access of stray direct current, which can only dissolve the metal where it leaves a buried pipe to enter the surrounding earth. Stray-current electrolysis was, therefore, admitted to be impossible under the circumstances.

The only inference that could be drawn from the facts noticed by the party was that the observed corrosion could only have been caused by the chemical activity of the solutions of the so-called alkaline salts.

It was further pointed out that it had also been recognized for several years past, by practising civil engineers, and more recently by public authorities and the public generally, that these alkaline salts, the sulphates, chlorides, carbonates and bicarbonates of magnesium, calcium and sodium, which are widely distributed through the soil of western Canada, are very corrosive to concrete made of Portland cement, no matter how carefully the concrete is mixed and deposited.

Chemical research work started about a year ago under the direction of W. Nelson Smith, M. E., and conducted personally by Dr. J. W. Shipley in the laboratory of the University of Manitoba, has brought to light many facts respecting the behavior of commercial cast iron, lead, and copper, in contact with neutral solutions of the above so-called alkaline salts. This research is now so far advanced that a definite report on the main outstanding facts will be forthcoming during the present summer.

Voltage Regulation and Insulation for Large Power, Long Distance Transmission Systems

BY FRANK G. BAUM

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Heretofore the distance to which power could be transmitted has been limited. This limitation is now removed by a simple method of loading the line with synchronous condensers, so that the current and voltage may be kept practically in phase. High power factor and hence high efficiency result, and the voltage rises of the system are very much reduced, thus reducing insulation strains.

A standard frequency of 60 cycles is advocated for the national system, and 220,000 volts is proposed as standard for extra large-power, long-distance transmission. The system of regulation proposed will result in practically constant voltage at all points of the line at all loads. And power may be taken from or supplied to the line at any point, and the power over sections of the line or over the entire line may be reversed and the constant voltage system maintained.

A simple diagram is given, and this shows that for a 60-cycle, 220,000-volt line, the line-charging current supplies about two-thirds of the capacity current required for about 0.8 load or 320 amperes load current, and that for larger loads the synchronous condensers supply leading and for smaller loads lagging current. Thus it is seen that the transmission line has largely inherently the currents required for self-regulation, if we correct initially the power factor of the loads to near unity. Every induction motor added to the power system calls for a certain capacity current for correction of power factor to reduce the losses from motor through to the power station. Every synchronous motor added, instead of an induction motor, helps in the economy all along the line, improves the service and reduces the menace resulting from large lagging currents. Every synchronous motor added becomes an asset to the entire system. Power factor correction should be done largely at load centers, the final correction and regulation being accomplished by the transmission line capacity current and the synchronous condensers.

The advantages of such a system are Simpler and cheaper generators, transformers standardized for one voltage, insulation strains reduced and a safer system results, and with constant voltage the flow of power has the greatest possible flexibility. (So far as known the proposal and method of presenting is new).

This will give a system power transmission comparable to railway transportation, with a flexibility not possible in the or·inary system which does not have the constant voltage feature.

The problems of ·he line insulation are discussed, and especial attention is called to the necessity for low air and leakage resistance stresses. The leakage resistance stresses are most important. For best results these should be distributed as uniformly as possible over the insulator surfaces, under the worst conditions. Results of a large number of tests are gi en.

A new diagram is given which results from analysis of experimental data, from which the characteristics of long strings of insulator strings may be calculated, knowing the constants of the units relatively.

The wet and dry arc-over may be controlled if desired, as shown by the illustrations, but it is believed best to strive for the elimination of arcs, except for cases of accident.

While the present insulators with some form of shielding or grading (and with a system of regulation as given in Part I) will no doubt give more satisfactory results for 220,000 volts than is now obtained on lower voltage lines, it is desirable that further work be done with a view to crystallizing the best method of handling the line insulation. There is here an opportunity for some pioneer work, which will give us all that is desired, resulting in a high factor of safety for the line insulation.

I. VOLTAGE REGULATION OF TRANSMISSION LINES

Introduction

WHEN a power man is asked how far electric power may be transmitted, he often qualifies his answer by restricting the frequency, or the per cent power loss, or by saying one mile for each 500 or 1000 volts between wires, etc., etc. The only real qualification should be that we can transmit power as far as economy dictates. That is, we are now, as herein shown, able to transmit power as a commodity from its points of production to the places of its use without restriction as to distance, etc.—*so long as it pays to transmit the power*.

Engineers are prone to pay too much attention to the losses or percentage losses in transmission. But the real answer to the transmission problem—assuming it now possible to give constant service—is the value of the product at the end of the transmission. A man may start out with a truck load of gasoline and transport it so far that only one-half, say, remains, but the remainder—not diminished in quality—may be very profitably used. In many operations only a small fraction of the energy measured in kw-hr. is used at the end of the cycle and yet the operation may be very profitable.

In the electrically driven trains, machine tools—in the incandescent lamp, etc., only a small part of the energy is finally utilized. In wireless transmission of messages only an extremely small fraction of the transmitted energy is received, and yet it is successful. (Wireless transmission of large power is not possible and wire transmission is a refinement over wireless transmission.) The electric transmission of power

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may be at high efficiency, even for long lines as shown here, and give good service.

Let us suppose we have a cheap source of water power and that the losses in transmission are 10 per cent average for each 200 miles. Then the efficiency of transmission for each 200 miles—giving practically perfect service as will be shown—will be approximately as follows (conductor area remaining constant):

Section	Average Loss	Efficiency & Power
0 to 200 miles....	10 per cent	90
200 to 400 "	9 " "	81.9
400 to 600 "	8 " "	75.35
600 to 800 "	7 " "	70.08
800 to 1000 "	6 " "	65.78

For 1000-mile transmission this shows about two-thirds of the power delivered or one-third lost. The above assumes all the power carried the full 1000 miles. If power is supplied at 200 miles, the efficiency would be 90 per cent, etc. At 600 miles we have an efficiency of transmission of about 75 per cent. For distributed loads the efficiency would be higher.

The cost will not be prohibitive if we have a cheap source of power going to good markets as will be shown by the following:

The capital cost of power at the generating station we may take, say, at $150 per kw., and the transmission cost, including synchronous condensers and their transformers, may be $15 per kw. per 100 miles, or 10 per cent increase in the power cost for each 100 miles, or $300 per kw. (per kw. generated) for 1000 miles. But since the power delivered at 1000 miles will be about two-thirds, then the capital cost per kw. delivered will be $450. The above assumes 100,000 to 200,000 kw. (or more) transmitted per three-phase circuit, which may be successfully done (using aluminum for the smaller and copper for the larger power), as we shall see at 220,000 volts.

There may be a very large market, say five hundred miles from the power source, and the transmission system built for that condition. But another power load may be 50, 100 or 200 miles away and the justification for the added transmission must be that this step must pay the cost of the power at the end of the 500-mile transmission and all of the remainder of the transmission. Such a system may grow to a national power system.

220,000 Volts Proposed as Standard for Large Power and Long Distance

Since we can transmit at this voltage so large an amount of power (a thousand miles if economical) over one circuit, and a very large system would want for service insurance at least two tower lines with four circuits, giving a capacity of 400,000 to 800,000 kw. or more, it seems that for this reason it may be best to adopt 220,000 volts as standard for the national transmission system, just as the railroads have adopted a standard gage. It will be shown that so far as other restrictions are concerned we may go to higher voltages, but the economic limitations may be reached by 220,000 volts, when we consider the value of standardization, the service insurance of multiple circuits, the amounts of power available at certain places, or the demand of a given market.

Heretofore I have always said that we would go to higher voltages, but I now believe, for the above reasons, that 220,000 should be standard for extra high-voltage systems. And it would be advantageous if 220,000-110,000-55,000 could be generally adopted, in order that auto-transformation may be used economically.

A Standard National Electric Power System
Standard Frequency

To have a national electric power system requires first standardization of frequency. Since 60 cycles is generally advantageous for generators, transformers and distribution, I will assume that this is the frequency of the very long-distance transmission. It is generally assumed that this frequency is disadvantageous for long transmission lines on account of voltage regulation, but it will be seen that all regulation requirements can be very successfully met with 60 cycles. I therefore believe it will be best to standardize on 60 cycles.

Constant Voltage at all Points of Lines

It will be necessary for the successful long transmission line to have practically a uniform voltage for all points of the line—not only for one load but for all loads. This voltage can be controlled within 3 per cent from no-load to full load and with no greater variation for any points on the line. The standard transmission system must provide for power being supplied to the lien and for loads to be taken off at certain points, just as does a railway system. The system must be such that the power loads supplied to the line or taken from the line may vary and that the flow of power over sections may be actually reversed, or the flow of power over the entire line may even be reversed—without disturbing the voltage regulation necessary to give good service at all points. There is nothing experimental about the proposal as synchronous condensers for voltage regulation for fairly long lines were used as early as 1904 on what is now the system of the Pacific Gas and Electric Company, to regulate voltage in an emergency for transmission of power over 300 miles of line at 44,000 volts. The present plan differs from the ordinary plan in that synchronous condensers are located, say every 100 miles, and with these condensers the current and voltage would be maintained practically in phase.

It will be seen that the maintenance of constant voltage at all points is not a difficult matter and in doing this we get rid of a lot of other troubles and

expense,—such as voltage rise due to dropping loads, transformer variable ratios, voltage regulators, etc., *and reduce the insulation strain.* The successful very long lines must provide for keeping the current and voltage practically in phase at all points of line.

If engineers and operating men can standardize the frequency and the voltage so as to give constant service, and the insulation of the transmission lines is made so that the line is as successful as the transformers, then we may see the real era of very long, high-power transmission systems in the near future. The 220,000-volt lines now being built are therefore extremely important; and extreme care is being given to all the questions, not only in view of the importance of the lines being built, but also because of the effect on the service of these lines on the transmission industry as a whole.

Voltage Regulation of Transmission Lines*

It is necessary to decide on the voltage regulation of the system before we can know what ordinary and extraordinary strains may come on the insulation of the transmission line; hence this subject is treated first.

In Fig. 1 is shown the regulating diagram for a 200-mile, 220,000-volt line, for 400 amperes current. It is shown there that without synchronous condensers for a power factor of load of 0.95 the generator voltage would have to be 157 per cent of receiver voltage. At no-load the generator voltage would be about 86 per cent if all charging current is carried by generator. Even for non-inductive load the generator voltage at full load would have to be raised 36 per cent above receiver voltage. Now this extra generator voltage is part of the capacity of the generator and costs money. Restricting the generator voltage increase to the 10 per cent required to make up the dissipated energy on the line, requires synchronous condensers of about 80,000 kv-a. at full load, but about one-half this amount is required to correct the power factor of the load. In this figure and those following, the explanations are given with each case. Fig. 1 is given largely to show that it is impossible to transmit power over long distances and give satisfactory service without synchronous condensers.

*See: The use of Aluminum Line Wire and Some Constants for Transmission Lines, A. I. E. E., May, 1900, by Dr. F. A. C. Perrine and F. G. Baum.

A Simple Diagram Showing the Regulation of a Transmission System for any Load and any Power Factor, *Electrical World*, May 18, 1901, by F. G. Baum.

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Alternating-Current Calculating Device, Second Edition, 1903, by F. G. Baum.

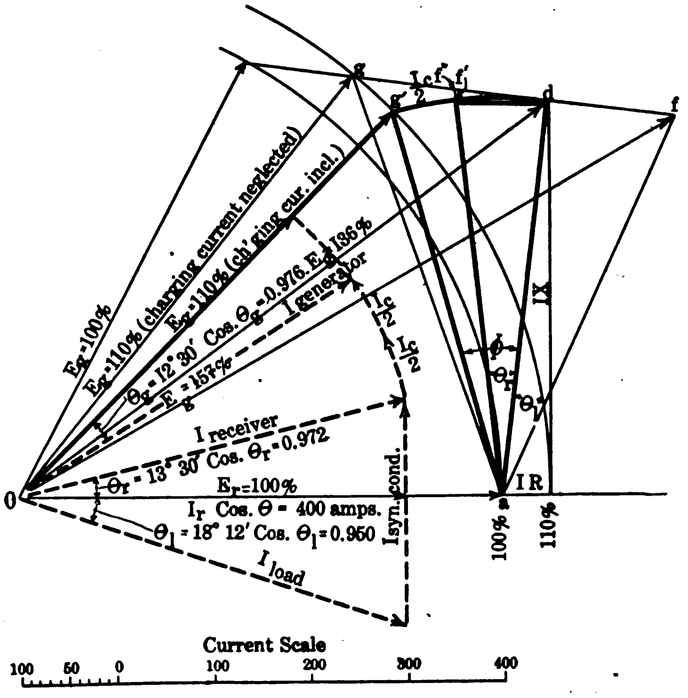


Fig. 1—Regulation of Line with Transformers at Each End

CONDITIONS:

Length of line = 200 miles. Receiver volts E_r constant at 200,000. Charging current 136 amperes.

I Cos θ at receiver = 400 amperes. Power delivered = 138,600 kw.

$I\,R$ pressure including transformers at each end of line = 10 per cent E_r (approx.)

$I\,X$ pressure including transformers at each end of line = 80 per cent E_r (approx.)

RESULT:

CASE 1. Charging current neglected. With no synchronous condenser at the receiver and a load power factor of *unity*, the generator voltage $E_g = o\,d$ = 136 per cent E_r = 272,000 volts at full load.

CASE 2. Charging current neglected. With no synchronous condenser at the receiver and a load power factor of 0.95 lagging, the generator voltage $E_g = o\,f$ = 157 per cent E_r = 314,000 volts at full load.

CASE 3. Charging current neglected. With a synchronous condenser at the receiver to maintain a generator voltage $E_g = o\,g$ = 110 per cent E_r = 220,000 volts at full load, the receiver power factor would be 0.89 leading (cos. angle *dag*.). The ratio $f\,g/a\,d$ gives the synchronous condenser current necessary to correct the power factor from 0.95 lagging to 0.89 leading (336 amperes approx.).

CASE 4. Considering one-half of charging current as supplied at each end of the line, and a synchronous condenser at the receiver to maintain a generator voltage $E_g = o\,g'$ = 110 per cent E_r = 220,000 volts at full load:

With a as center, draw circular arc $d\,g'$. The length of arc $d\,g'$ is equal to $a\,d \times \Phi$ (in radians).

The angle Φ measures 23 deg. = 0.401 radian. $a\,d = \sqrt{0.10^2 + 0.80^2} \times E_r = 0.806\,E_r$. $d\,g' = 0.806\,E_r \times 0.401$ = 32.3 per cent E_r.

The charging current $I_c\,X/2$ = 13.3 per cent (approx.), hence the correction to be made by the synchronous condenser is 32.3 − 13.3 = 19.0 per cent.

Lay off $d\,f'$ = 19.0 per cent E_r and draw $a\,f'$ and $d\,f'$. Note that the condenser current must be at right angles to $a\,d$, so for practical purposes we may use the point f'' instead of f'.

The power factor of the receiver is 0.972 leading (cos. angle $d\,a\,f''$). The ratio $f\,f''/a\,d$ gives the synchronous condenser current necessary to correct the power factor from 0.95 lagging to 0.972 leading (230 amperes approx.).

NOTE: Fig. 1 is given mainly to show that very long transmission without synchronous condensers is not practicable. The figure as drawn is not absolutely accurate except when $E_r = E_g$, but the error is not material.

Fig. 2 gives the fundamental basis for regulation for constant voltage by using distributed capacity, of such magnitude that the line current and voltage are always practically in phase. This makes the reactance pressure always tangent to the voltage circle, the reactance voltage being represented by the circular arc connecting the ends of the line pressures.

Fig. 3 shows that, for 60 cycles, 200,000 volts and 400 amperes transmitted, the line charging current gives full correction at about 0.8 load, and that the synchronous condensers at full load must supply capacity current of about one-half the charging current. Thus it is seen that the line supplies a large part of the charging current required for regulation. At loads below 0.8 the synchronous regulators supply lagging current. It would be preferable to call the synchronous condensers "synchronous regulators." (This proposal for regulation and the method of presenting it are new, so far as known.)

Thus it is seen that the transmission line has largely inherently the currents required for self-regulation, if we correct initially the power factor of the loads to near unity. Every induction motor added to the system calls for a certain capacity current for correction of power factor to reduce the losses from motor through the power station. Every synchronous motor added, instead of an induction motor, helps in the economy all along the line, improves the service and reduces the menace of large lagging currents. Every synchronous motor added becomes an asset to the entire

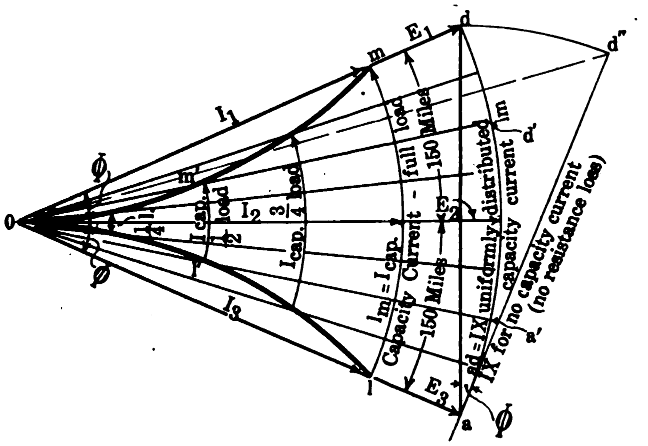


Fig. 2—Regulation of Line Alone

Uniformly Distributed Capacity Current to Correct Voltage at all Loads

CONDITIONS:

Length of line, 300 miles. Voltage at all points constant at 200,000. Charging current 200 amperes.

Energy current delivered to line, 400 amperes. Power delivered to line, 138,600 kw.

No resistance loss and no energy dissipated along the line.

$I\,X$ pressure equal to approximately 80 per cent E_3 and measured by arc $a\,d$.

RESULT:

If no power is lost along the line, then current $I_1 = I_2 = I_3$ and they are in phase with voltages E_1, E_2 and E_3, the power factor being unity. If reactance pressure is 80 per cent of E_3, then arc $a\,d = 0.80\ o\,a$ and angle $2\,\Phi = 0.80$ radian $= 46$ deg. (approx.). The uniformly distributed capacity current is everywhere at right angles to the voltage and the summation is shown by the arc $l\,m$. If $o\,l$ represents 400 amperes or the energy current, then $l\,m = 2\,\Phi \times o\,l = 0.80 \times o\,l = 0.80 \times 400 = 320$ amperes, the uniformly distributed capacity current necessary to maintain conditions as set down above.

At one-half load the reactance pressure, which corresponds to one-half load $a\,d$ is reduced one-half to $a'\,d'$. This reduces the angle between E_1 and E_3 by one-half. Since the current is reduced by one-half $o\,l$ is reduced to $o\,l'$ and the arc $l'\,m'$ becomes one-quarter the length of $l\,m$. Thus it is seen that the capacity current required varies as the square of the load current.

If there were no capacity current on the line at full load, then the reactance pressure would be $I\,X = a\,d''$ at right angles to E_3. The arc $d\,d''$ shows the voltage correction due to the summation of capacity currents flowing over the line reactance.

Note that the angle between $a\,d$ and $a\,d''$ is always equal to one-half the angle between E_1 and E_3.

CONCLUSION:

To have constant voltage at all points on the line requires that the capacity current uniformly distributed over the line be varied along the curves $o\,l'\,l$ and $o\,m'\,m$ from no-load to full load, this variation being as the square of the load current. This maintains the voltage and current practically in phase at all points of the line, and this condition is necessary for successful long-distance transmission of power.

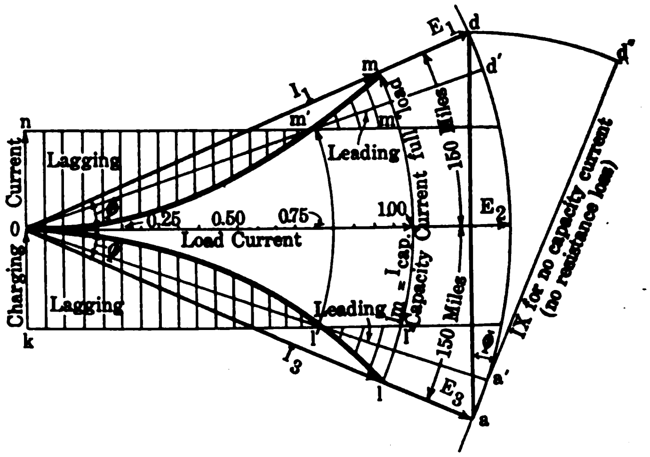


Fig. 3—Regulation of Line Alone

Line-Charging Current Supplemented by Uniformly Distributed Capacity or Uniformly Distributed Inductance.

CONDITIONS:

Length of line, 300 miles. Voltage at all points constant at 200,000. Charging current, 200 amperes.

Energy current delivered to line, 400 amperes. Power delivered to line, 138,600 kw.

No resistance loss and no energy dissipated along the line.

$I\,X$ pressure equal to approximately 80 per cent E_3 and measured by arc $a\,d$.

RESULT:

If no power is lost along the line, then load current $I_1 = I_2 = I_3$. The line-charging current is shown by the line $k\,n$ and is uniformly distributed along the line. At a point of approximately 80 per cent load, the line-charging current $l'\,m'$ furnishes a uniformly distributed capacity current, which makes the voltage equal at all points along the line. (See conclusion, Fig. 2).

From 80 per cent to full load uniformly distributed capacity current must be added to the charging current, as shown by the lines between $m'\,m''$ and the curved line $m'\,m$ and also between the line $l'\,l''$ and the curved line $l'\,l$. The power factor would be unity.

To correct accurately the voltage from no-load to 80 per cent load we would have to have distributed inductance, as shown by the lines drawn between $n\,m'$ and the curved line $o\,m'$ and also between the line $k\,l'$ and the curved line $o\,l'$. The power factor would again be unity.

CONCLUSION:

The above would give accurately the regulation desired, but we have no method of adding distributed capacity or inductance. The best we can do is to approach the desired result by adding synchronous condensers which may operate as capacity or inductance at the will of the operator.

NOTE:

Thus far we have not considered resistance losses, but they are easily taken into account as will be shown.

This adjustable "loading" of the line to maintain the current practically in phase with the voltage is comparable to the "loading" of telephone lines for long-distance circuits.

system. Power factor correction should be done largely at load centers, the final correction and regulation being accomplished by the transmission line capacity current and the synchronous condensers.

There are many places where synchronous motors could replace induction to great advantage. The electrical manufacturers and the power companies should cooperate in developing simplified types of synchronous motors for constant speed work.

The advantages of such a system are: Simpler and cheaper generators, transformers standardized for one voltage, insulation strains reduced and a safer system results, and with constant voltage the flow of power has the greatest possible flexibility.

Figs. 2 and 3 show that it is necessary for constant voltage at all points of the line that the voltage and current be maintained practically in phase. Fig. 4 applies these conditions practically to a 300-mile line and Fig. 5 to a line 800 miles long. The diagram is very simple and may be extended for any line length.

Conclusion

Such a system of constant potential transmission is practical, and is the only practical way of giving perfect service for long lines. Retransforming or regeneration or direct-current schemes for long-distance transmission will not give as good service and the shocks that are likely to come on the line are much greater than for the constant potential system. Such a system of "loading" the transmission line to rotate the current through approximately the same angle as the pressure is rotated is necessary for all very long distance transmission, thus causing the reactance pressure to be always tangent to voltage circle. This "loading" to maintain the current and voltage approximately in phase eliminates the question of the natural periodicity of the line, and hence the frequency may be selected independently of this point.

The voltage being constant there is a gradual decrease of current to make up the dissipated energy of the line. The angle between the generator and receiver voltages of a 150-mile section will be about 23 deg. at full load, 60-cycle, and the angle decreases per 150-mile section as the current decreases.

The power factor of line is good, being 0.99 or better from about 80 per cent to full load, and hence efficiency of line is 90 per cent for 200 miles, and 90 per cent for each section of 200 miles, with the result that power may be transmitted 600 miles with an efficiency of about 75 per cent and 1000 miles at an efficiency of about 65 per cent. For distributed loads the efficiency would be higher.

Such a system, with say three or four circuits, and synchronous condenser and switching stations about every 100 miles, may have automatic disconnection for any 100-mile section of each line without disturbing the service. Short circuits should be easily handled.

The synchronous condensers "tie down" the points of the system. Any tendency to raise or lower the line voltage is instantaneously counteracted by the condenser—in this respect acting like an "electric gyroscope."

Since transformers can be designed so that increase of line voltage gives a very rapid increase of magnetizing current, we have here, as well as in the synchronous condensers, automatic magnetic brakes acting against increases in voltage.

Corona losses increasing with voltage, if size of

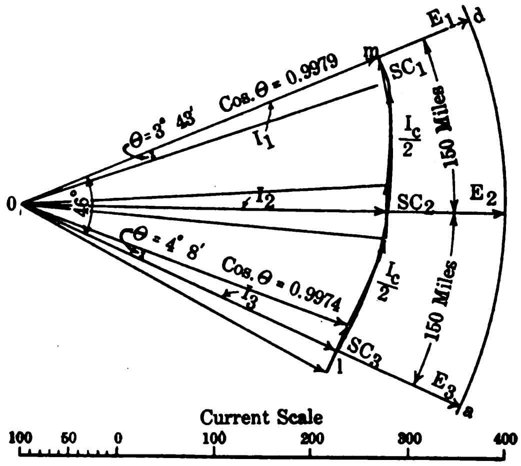


Fig. 4—Regulation of Line Alone

Leading or Lagging Current Added at Middle and Each End of Line

CONDITIONS:

Length of line, 300 miles. Voltage at middle and each end constant at 200,000. Charging current, 200 amperes.

Energy delivered to line, 400 amperes. Power delivered to line, 138,600 kw. Total energy loss including $I R$ = 10 per cent.

$I X$ pressure equal to approximately 80 per cent E_1 and measured by arc $a d$.

RESULT:

Since the arc $a d$ is 80 per cent of the radius $o a$, the angle $d o a$ is 0.8 radian = 46 deg. (approx.).

Since the voltage at each end of the line is constant, the energy loss will appear as a reduction in load current, diminishing in direct ratio to line length, hence if $I_1 = 400$, $I_2 = 0.95 \times 400 = 380$, $I_3 = 0.90 \times 400 = 360$.

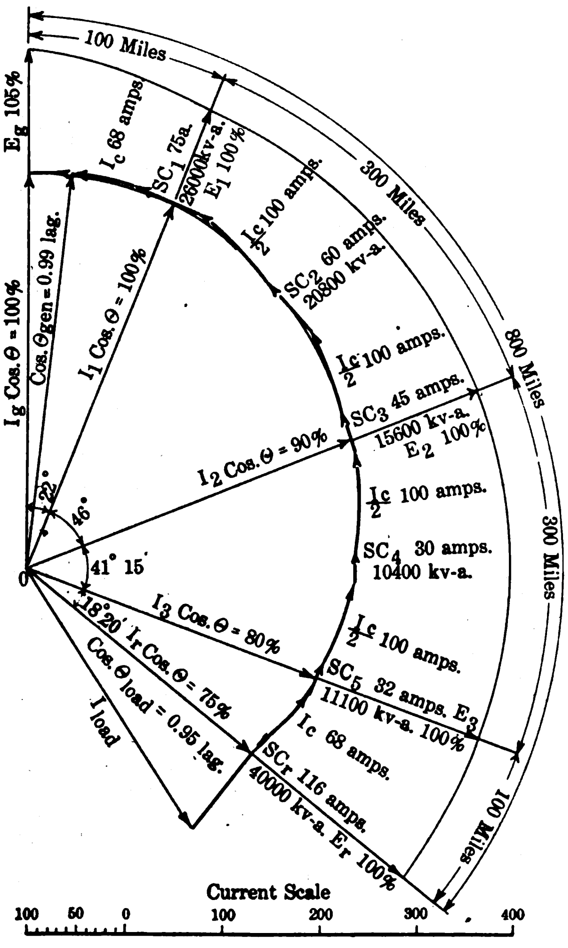
The curve $l m$ represents a uniformly distributed capacity current which will give equal voltage at all points on the line at full load. The length of $l m$ is approximately equal to $380 \times 0.8 = 304$ amperes. The charging current supplies 200 amperes of capacity current, leaving 104 amperes to be supplied by synchronous condensers. One-half of this is to be supplied by a synchronous condenser in the middle of the section, one-quarter by the generator, if this is the first section of the line; and if not, by the synchronous condenser at the end of the section toward the power house. The remaining quarter is to be supplied by a synchronous condenser at the far end of the section. This synchronous condenser, however, will be the same capacity as the one at the middle of the section, the excess capacity to care for load power factor correction if it be the terminus of the line or to furnish the initial capacity current required in the next 300-mile section of line. This makes the condensers 18,000-kv-a. $(52 \times 200{,}000 \times \sqrt{3})$ capacity, or say 20,000-kv-a. to afford a safe margin, for each 150-mile section of line where there are no transformers or other apparatus to change the $I R$ and $I X$ pressures as set down above. If transformer resistance and reactance are included, the diagram will have to be modified to fit a section of line enough shorter than 300 miles, so that $I X$ and $I R$ including transformers are 80 per cent and 10 per cent respectively. This lowers the charging current and increases the size of synchronous condensers required for the section. In considering the 300-mile section, the transformers for the synchronous condensers are small and the magnetizing current will be supplied by the condenser. The section is considered as if no transformers were present.

The voltage on a 300-mile section at no-load varies less than 1 per cent, if the charging current is supplied one-half at the middle and one-quarter at each end of the line. The power factor at each end of the 300-mile section will be practically 0.99 and the entire section will have a power factor between 0.99 and unity, from 80 per cent to full load. (See Fig. 3).

wire is chosen near the corona point, will also automatically act against increases of speed and voltage.

The voltage strains on insulators, switches and transformers of such a system will be much less than where the constant potential control does not exist, and hence we very largely solve the insulator problem by the voltage control.

The "loading" of the line with transformers designed for a rapid rise in magnetization with increases in voltage, the transformers having secondary or tertiary windings connected delta, connected to synchronous condensers at proper distances, will reduce the insulation rises so that 220,000-volt lines will have less insulation overstrains than present high-voltage lines. Adding to this the improvement to be obtained by decreasing the duty on the line wire insulator units, assures the success of very long transmission lines—practically removing the distance limitation to electric transmission. This method of transmission also eliminates the necessity for further consideration of d-c. transmission as the a-c. system has the advantage of the constant-voltage feature, for any conditions of loads and power supply, and has other advantages over the d-c. system.



CONDITIONS:

End sections of line each 100 miles long. *I X* pressure including transformers, 40 per cent. *I R* pressure including transformers, 5 per cent. Charging current, 68 amperes.

Intermediate sections of 300 miles length. *I X* pressure, 80 per cent. *I R* pressure, 10 per cent. Charging current 200 amperes.

Full-load generator volts, 105 per cent E_r. Voltage constant after first synchronous condenser station.

I cos θ at generator is 100 per cent. *I* cos θ at first synchronous condenser station is 100 per cent and then decreases uniformly along the line to care for energy losses. (Note that cos θ varies only slightly from unity, and that the current tapers from 100 to lower values to make up resistance losses as shown.)

RESULT:

Generator Section: See Fig. 1 which shows a 200-mile section with generator and transformers at one end and condenser and transformers at other end. Apply the generator end one-half of Fig. 1 to this case, modifying it as to generator voltage and consider that the generator carries only one-quarter of the capacity current instead of one-half as shown, the other one-quarter to be supplied by the first condenser in the adjoining section.

Second Section: Conditions exactly as in Fig. 4.

Third Section: Current is now 90 per cent *I*, hence the *I X* pressure is 90 per cent of its value in section two = $0.90 \times 0.80\ E_r = 0.72\ E_r$. The arc length representing this pressure is therefore reduced and the angle becomes 0.72 radian = 41 deg. 15 min. The capacity current required is 360×0.72 = 260 amperes (approx.). The charging current is 200 amperes, leaving 60 amperes to be supplied by the condensers as in section two.

Receiver Section: Current is now 80 per cent *I*, hence the *I X* pressure is 80 per cent of its value in the generator section = $0.80 \times 0.40\ E_r = 0.32\ E_r$. The angle now becomes 0.32 radian = 18 deg. 20 min. The capacity current required is 320×0.32 = 102 amperes (approx.). The charging current is 68 amperes, leaving 34 amperes total to be supplied by the condensers at the ends of the section.

If the load power factor is 95 per cent lagging, then the terminal condenser current will have to be increased by 99 amperes to rectify this load, and the kv-a. capacity would be $(17 + 99) \times 200{,}000 \times \sqrt{3} = 40{,}000$ kv-a. approximately.

NOTE: Power may be delivered to or from the line at any point. The load currents and synchronous condensers may be readjusted to care for the new conditions so that the voltage may remain practically constant. The power flow of the entire line may even be reversed and the constant voltage conditions retained.

FIG. 5—REGULATION OF COMPLETE TRANSMISSION SYSTEM

II. INSULATION OF TRANSMISSION LINES

The early transmission systems used the pin type of insulator, and lines up to 80,000 volts successfully used this type. Then the demand for higher voltages brought out the disk suspension insulator. Mechanically the disk insulator at first view seems an impossibility. But the insulator men have solved the difficulties and deserve a great deal of credit for the result. Suspension types can now be made with ultimate strength of 7000 to 20,000 lb.

The insulator men have carried a large burden during the development period of the insulator. Sometimes this burden is made greater by the engineer or operator asking for some particular design which may not be as good as standards already made. The desire of the individual to write his name on something is at the bottom of many failures in engineering as well as along other lines of human endeavor. On the other hand pioneer work is required when conditions change and designs must follow fundamental laws.

When the type of insulator for the high voltages changed to the disk type, it was assumed that the addition of more voltage merely required more units. But it was soon found that the results were not at all in proportion to the number of units in the string.

Investigating the cause it was found that the voltage tended to "pile up" on the line unit.

A very large number of tests has been made on voltage distribution, with various arrangements of controlling gradient, and also to determine the arc-over characteristics, both dry and wet, for various control arrangements. These tests were made in the following places and under the supervision of the following men:

Stanford University, Cal. Prof. Harris J. Ryan.

General Electric Co., Pittsfield, Mass. F. W. Peek, Jr.

Ohio Insulator Co., Barberton, Ohio. A. O. Austin.

Thomas & Sons, Lisbon, Ohio. R. H. Marvin.

Locke Insulator Co., Victor, N. Y. K. A. Hawley.

Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa. C. Fortescue.

I very greatly appreciate the interest shown by these men and acknowledge with thanks their hearty cooperation.

In the following pages the insulation problem is discussed in some detail, and the discussion is followed by an appendix giving the results of a large number of tests, the conditions for which are stated. Only a few of the tests made are given.

Insulation of Transmission Line

In the insulation for transmission lines we must consider the following:

1. The air insulation strength.
2. The porcelain insulation and mechanical strength.
3. The voltage distribution.
4. The leakage resistance gradient over the surface of the insulators.
5. Insulation of switches, transformers, etc.
6. Wet and dry arc-over of line insulation.

1. The Air Insulation

Engineers and operators have been prone to blame the insulation difficulties on the air. But as a matter of fact, air is, except where we have salt spray, etc., a very good insulator. Peek (whose work on Dielectric Phenomena is a classic in engineering) has shown in his book that it requires only about three inches of air between 10-inch spheres to prevent break-down for 130,000 volts to ground, which is about the voltage to ground for a 220,000-volt line. Two 20-inch spheres, spaced two feet, give a factor of safety of about four. We are using over six feet from wire to ground at the towers (15 feet between wires in the span), but we do not get a factor of safety commensurate with the distance.

With wires about 1 inch in diameter we need never fear break-down of the air between the wires a few feet away from the insulators, and if it were not for the reduction in the equivalent spacing at the tower, due to the insulator breaking the distance into a number of parts, with unequal stress on the separate units, we could reduce our spacing in the span and thereby reduce the height of the towers.

Fig. 6 shows the voltage air gradient for a wire 0.91 in. in diameter at 220,000 volts, and also the gradient for a wire 0.47 in. in diameter for 110,000 volts. It is seen that the gradient is very high near the surface of the wire, and very nearly the same in the two cases. The break-down value of air is about 20 kv. (effective) per cm. (The size of line wire is purposely chosen so that increases of voltage much above normal will increase materially the corona losses, as this is a safeguard in case of rise in voltage due to speed rise or otherwise). At a distance four cm. from the surface of the 220,000-volt wire the gradient is only about 4 kv. per cm. In the span, away from the insulators,

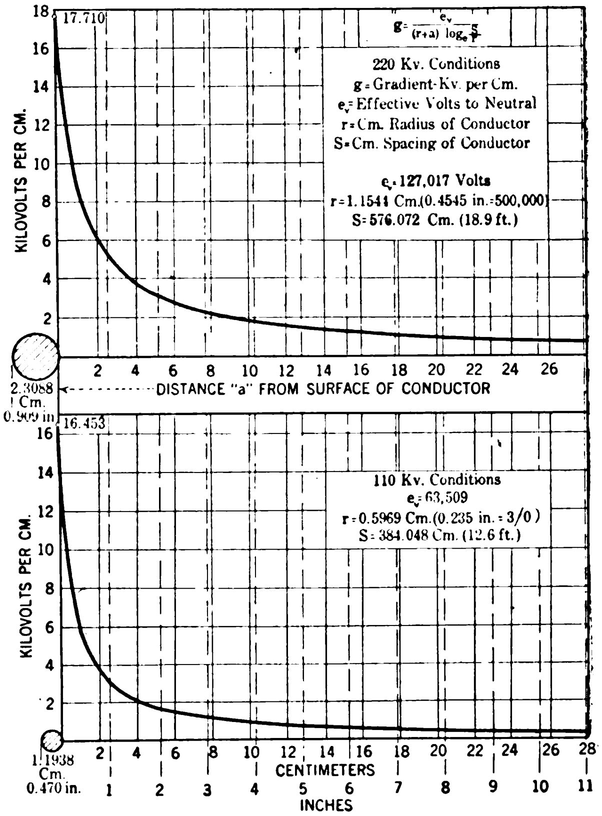


Fig. 6—Air Gradient for 220,000- and 110,000-Volt Conditions

any tendency to produce visual corona has the effect of enlarging the effective diameter of wire so far as surface gradient and break-down are concerned, hence the air in the span does not break down for any voltages that may be reached in operation.

Coming now to the line clamp fittings and insulator pin of the first unit, we see that we have here very high air gradient, due to small diameters, angles of bolts, fittings, and also due to the small pin of the bottom insulator. When excess voltages come on the line they pile up most of it at the insulator units near the line wire. This breaks down the air where it is highly stressed at the line fittings, and the air breaks down serially from one unit to another, by transferring the high electric stress from one

unit to another in the string. (Corona also forms acids which attack the metal fittings.) It is necessary to prevent incipient corona pluming or arcs at the insulators, if the transmission line is to be fully successful—by which I mean the insulation of the line must be such that the line should give as good operating results as the transformers or other transmission apparatus. Of course, the line is subject to damage maliciously, or due to accident, but neglecting these, the line should be made as reliable as the remainder of the system.

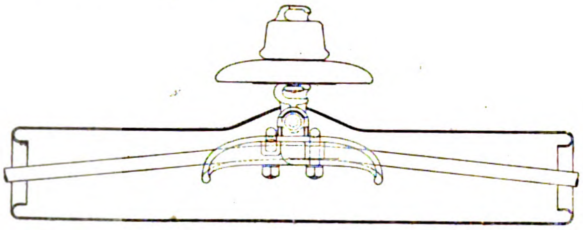


FIG. 7—LINE SHIELD

Attempts made to reduce the air grading at the pin and fittings by the use of "shields" (these will be explained later) have led to fairly satisfactory results. And it seems necessary to shield the line wire and fittings by enlarging the conductor diameter by some such cylindrical (or double cone or plane) shield as shown in Figs. 7 and 8. With such a shield the visual corona near the insulator may be raised far above the operating voltage. The fittings of the insulators of the string should also be designed to prevent high air stress.

2. THE PORCELAIN INSULATION

Porcelain when well made is a good insulator, and will not puncture under the stress conditions placed on it, if the other elements in the insulation are cared for. The metal fastenings to the "cap and pin" disk types of insulators add a mechanical depreciation factor because expansion and contraction are not the same for the porcelain and the metal parts, and the cement used to fasten the parts together. By careful manufacture, a very tough porcelain can be made, in which depreciation from expansion and contraction can be very much reduced. Careful selection and working of the clay, and sufficient time in firing, give a very high-class insulator product.

Impregnating the cement, to prevent absorption of moisture, has given good results, according to Mr. E. E. F. Creighton. Some means of keeping the moisture out of the cement, and careful mixing and setting of the cement initially, will no doubt reduce the mechanical failure due to these causes to very low values. I have always contended that we should finally obtain insulators that do not depreciate.

In the link type of fastening the mechanical depreciation from expansion and contraction is very largely reduced, but in the types now made we are restricted to small diameter of metal parts, and it is necessary on high-voltage lines to shield the links—at least those in the lower part of the string. (Fortunately this also improves the grading of the string as will be seen later).

The depreciation, due to expansion and contraction, is largely one of cost, and as it is a slow process and we have a factor of safety in the number of units in the string, we may dismiss the mechanical failure from the above causes as not affecting good service with good inspection.

The mechanical strength of all the standard insulators is from 7500 to 10,000 lb. and over, and these can be increased 50 or 100 per cent, where necessary, so that we have ample factor of safety for the mechanical suspension of the line wires.

3. THE VOLTAGE DISTRIBUTION FROM LINE TO GROUND

Figs. 12 and 13, and plates, D1, D2, D3 and D4 in the appendix, show the voltage gradients for cap and pin insulators and also for the link type. It is seen that, for the voltage corresponding to that between line wire and ground, the total pressure is divided very unevenly among the units. In the cap and pin string of 14 units the volts on the line unit are about 25,000, or about 2.5 times the average, but about six times the volts on the units near the ground end.

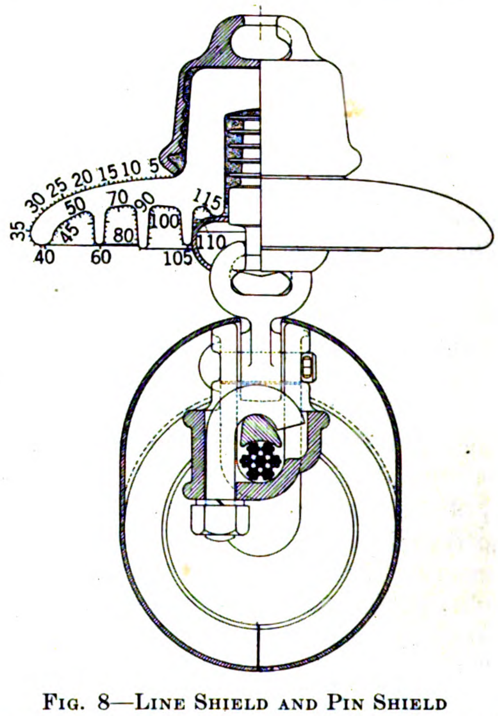


FIG. 8—LINE SHIELD AND PIN SHIELD

Numbers on edge of porcelain are for measuring leakage paths. (See Fig. 14.)

In the link type as shown, we have even a worse case of distribution of pressure, the maximum being about 37,000 or four times the average, and about ten times the stress on the units nearer the ground end of the string. This unequal stress on the units also causes unequal stress on the air, *but most important it does not distribute the leakage resistance along the string uniformly*. The maximum air and leakage stresses are from six to ten times the average. Reduc-

tion of the maximum stresses is therefore very important, and the result desired is that there will be more nearly average resistance stresses over the entire string, for the worst practical conditions.

Discussion of Cause of Poor Gradient and Method of Cure. Before we can say we fully understand a subject we must be able to express the facts in words mathematically or by diagram. Before we can rationally analyze an insulator we must know the factors which will limit the maximum stresses, which are:

1. The air stresses,
2. The leakage resistance stresses,
3. The insulator unit stresses.

The air stresses we know, as shown by Fig. 6, and to control this factor we must enlarge the conductor at the insulator, as shown in Figs. 7 and 8. The first controlling factor for satisfactory insulator characteristics then is that we must have metal parts designed to give low air stresses at the line wire, and also along the string of insulators, at least near the line wire end.

The unit stress affects the leakage stress and therefore it is very important also from this standpoint to reduce the maximum unit duties. The maximum leakage stress can be reduced (1) by reducing the unit voltage and (2) by enlarging the pin as shown in Fig. 8, and by the design of the resistance path from metal to metal as shown in Figs. 14 and 15. The enlargement of the pin and the shield over the line wire also reduces the maximum voltage on units near the line. The importance of reducing the maximum value of the leakage gradient is shown by the fact that in the pin type of insulator with the close fitting inner shell, better operating results are obtained by breaking off the inner shell. Here is one way of reducing the maximum leakage gradient, but the design should take this into account. This will be further discussed under (4): The Leakage Resistance Gradient over the Surface of the Insulator.

Hence, we have these two factors, (1) the enlargement of line wire and metal parts, and (2) the enlargement of pin, to start with to give us a satisfactory insulator. As will be seen, taking care of these two points helps the grading of the units fairly well.

The third factor, the grading of the units, requires that we be able to understand the reasons for the string gradient.

An attempt to explain this is here given in such a way that the drawing of a few lines may show the characteristic of any insulator string, knowing certain factors relatively only. It is not contended that we have all the facts necessary to explain every condition, but the method does give a simple and practical way of explaining many of the observed results, and it is hoped that the method given will lead to a further study of the subject, so that we may design or analyze the design of insulators in the same way as any other engineering problem.

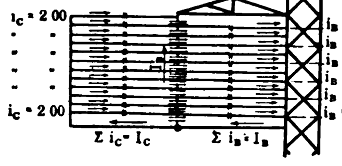
Figs. 9A, 9B, 9C and Table 9D give the explanation which results from a study of the distribution curves shown in Figs. 10 and 11.

(The individual insulator string may be regarded as a short section of transmission line with the Y voltage between ends, and with load currents, B, taken off at the different sections (or units) and load currents, C, being supplied to the sections. The load currents, B, depend on the voltage at the particular section.)

Referring to Fig. 10, which is a voltage distribution test curve of 14 cap and pin units, as shown by Curve I, this curve represents the voltage across the units, but as the voltage is proportional to the currents through the units the curve also represents, on some scale, the currents. Now the difference between the current through No. 14 and No. 13 units, for example, is the *net* current from the metal connecting parts to tower or ground. Taking the differences of the voltages and plotting them from the line $a\,a'$ we get the Curve II, which represents the net currents flowing from or to the string. It will be noted that below the fifth unit the currents flow from the string and above that point the currents flow from the air to the string.

In trying to find a physical explanation for this condition we draw the insulator string gradient and the air potential gradient on the left hand of Fig. 10, and from the knowledge gained from Curve II we see that where the net current from the metal part is zero the string potential and the air potential must be the same. Also we see that the summation of currents above the line where distribution Curve I cuts the average voltage, must be zero and that the current $c'\,a'$ at the top cap must be due to the current flowing to the cap only, as this cap is at zero potential. From this and from calculation of the potential drop through the air near the line wire (which we know follows a logarithmic curve) and from the fact that the air potential reaches zero at some distance above the crossarm in the span, we draw the approximate air potential. The difference between the air and string potential causes the currents to flow to or from the string as in Curve II.

We know that the currents from the metal parts to tower or ground would be approximately proportional to the voltage and hence a line $a'\,b$ may represent this current. Replacing the curved line II by the straight line III for simplicity of treatment and now calculating the gradient, we get Curve IV which approximates Curve I fairly closely. At the lower unit, due to the high electric stress, there is added potential to the lower unit. The difference between the line $a'\,b$ and $c'\,c$ represents approximately the currents from line wire to metal parts. This is the experimental basis for the discussion given in Fig. 9, in which 9B is supposed to represent the physical conditions, 9A the electrical and 9C the diagrammatic conditions. Fig. 11 gives the experimental results for the link type of units.



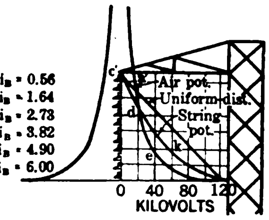


FIG. 9A FIG. 9B

ANALYSIS OF DISTRIBUTION CURVES

Fig. 9a shows an approximation of the different current paths with relation to the insulator string. Fig. 9b shows the potential. The curve of air potential shows the difference of potential between the surface of the conductor and the air at any given distance from the conductor. The straight line marked "uniform distribution" is the potential curve we would get for the insulator string if the voltage drop were uniform along the string. The curve marked "string potential" shows the actual voltage along the string from tower to conductor. Below the point d the air potential is lower than the string potential, causing a flow of current *from* the string, while above the point d the reverse is true and current flows *into* the string. This gives the line $c'\,c$ of Fig. 9c showing the difference between the B and C currents.

Inspecting the several currents shown in Fig. 9a, we have:

First: I_A which is the series current flowing through the string. This current varies as the voltage across the string and inversely as the number of units in the string. For convenience, we will assign a value of 10 to this current in a string of 12 cap and pin-type units with a duty of 10 kv. per unit or 120 kv. or the string.

Second: I_B which is the capacity current from cap to tower or ground, varying directly as the voltage between cap and ground. In a string of 12 cap and pin-type units where I_A is taken as 10, i_B, the current per unit, will vary from zero on the cap attached to the tower to approximately 6 on the cap of the unit next to the wire. I_B flowing in the string at any point is the summation of the currents from all caps between the point considered and the grounded end of the string.

Third: I_C which is the capacity current from the wire to each cap. Since the impedance path consists principally of the impedance of the air between the line and unit, and then in series through the insulator string, it is practically constant. In a string of 12 cap and pin-type units where I_A is taken as 10, i_C, the current per unit, will be approximately constant at 2. I_C flowing in the string at any point is the summation of the current to all caps between the point considered and the grounded end of the string, and may be considered as of the opposite sign to current I_B, because of the fact that the current is arriving *on* the insulator cap from the wire, and not flowing *off* the cap to tower or ground. (Note: Currents from cap to cap practically balance.)

TABLE 9D

Unit	Series Current in String I_A	Capacity Current Cap to Tower I_B In unit	I_B In string	Capacity Current Wire to Cap I_C In unit	I_C In string	$I_A + I_B - I_C$ In string
1	10	0	0	2.00	2.00	8.00
2	10	0.55	0.55	2.00	4.00	6.55
3	10	1.09	1.64	2.00	6.00	5.64
4	10	1.64	3.28	2.00	8.00	5.28
5	10	2.18	5.46	2.00	10.00	5.46
6	10	2.73	8.19	2.00	12.00	6.19
7	10	3.27	11.46	2.00	14.00	7.46
8	10	3.82	15.28	2.00	16.00	9.28
9	10	4.36	19.64	2.00	18.00	11.64
10	10	4.90	24.54	2.00	20.00	14.54
11	10	5.46	30.00	2.00	22.00	18.00
12	10	6.00	36.00	2.00	24.00	22.00

Table 9d shows the result obtained by using the values given above for I_A, i_B and i_C, that is 10, zero to 6 and 2, and applying to a string of 12 cap and pin-type units. The voltage duty is assumed as 10,000 volts per unit or a total of 120,000 volts for the string, and since the potential difference is proportional to the current flowing, we have a measure of the unit voltage duty when we know the current flowing. By taking the values of 10, 6 and 2 instead of some other set of numbers bearing the same ratio, the summation curve when plotted as in Fig. 9c, may be read directly in kilovolts duty per unit.

The relative values of the A, B and C currents as taken above hold good for cap and pin-type units when the unit voltage duty averages 10,000. For the Hewlett type insulators the B and C currents are approximately the same as in the cap and pin-type units, but the series capacity of the Hewlett is approximately only two-thirds that of the cap and pin type, hence keeping I_A at the same value of 10, the B and C values will be relatively larger and the ratio becomes $A : B : C = 10 : 0$ to $9 : 3$. From this relationship a curve for a string of Hewlett-type insulators similar to the curve in Fig. 9c may be plotted.

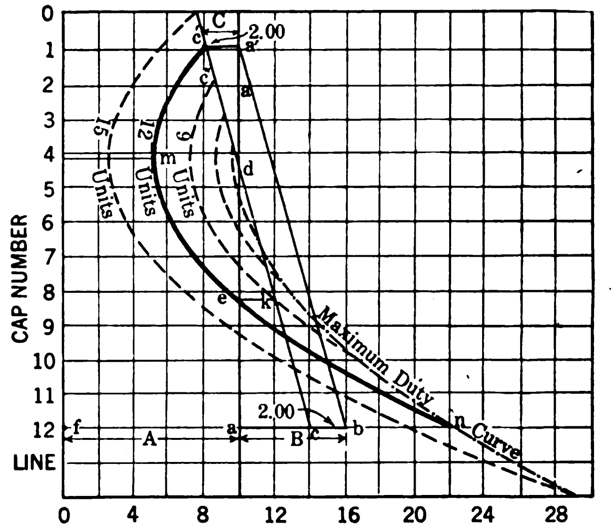


FIG. 9C

ANALYSIS OF DISTRIBUTION CURVES

To plot the voltage distribution curve lay off $a\,a' = I_A = 10$, a constant value for each unit. Next lay off $a'\,b$ such that $a\,b = i_B = 6.0$, thus making i_B vary from zero to 6.00. Next lay off $c'\,c$ to the same slope as $a'\,b$ so that $c'\,a' = c\,b = 2.0$. The distribution curve is now found by adding the values represented by $a'\,a$, a constant, and the values of $c'\,c$ as a s mmation, and is shown by the heavy line marked 12 *units*.

NOTE: In all discussions the B and C currents have been considered as varying along a straight line law. This, however, is not strictly true. In plotting the curve in Fig. 9c, it is seen that the line $c'\,c$ represents the *difference* between the B and C currents, and experiments have demonstrated that this *difference* follows closely along a straight line law. For the sake of simplicity, therefore, all have been considered as straight lines.

The point of minimum duty occurs at approximately one-third the distance from tower to conductor, and the voltage duty curve crosses the average duty line $a'\,a$ at a point e such that area $c'\,a'\,d$ is equal to area $k\,e\,d$. This means that above the point e, the voltages are balanced and therefore the only part of the string requiring grading is the unbalanced lower one-third.

Having given the curve for 12 units, the curves for other length of string where the duty remains the same average value of 10,000 volts per unit, may be drawn in for comparison. Since the minimum duty point is always about one-third the distance from tower to conductor, we may consider one-third of the change in length as applied at the tower end of the string and two-thirds at the line end.

The A current will remain at 10 as before since the total voltage across the string bears the same ratio to the number of units. The slope of $a'\,b$ will remain 6/11 as before because the rate of voltage change will not be altered. If we shorten the string by three units, taking one unit from the top and two from the bottom in order to keep the minimum point still one-third of the distance from tower to line, the value of the B current in the bottom unit will be $i_B/(11-3) = 6/11$ making $i_B = 4.36$. The ratio of the B current in the line unit to the C current is three to one, hence i_C becomes 1.45 and the first point on the curve for a nine-unit string is $c'' = 10 - 1.45$. Similarly we may plot a six or three-unit curve, or increasing the string length, a 15-unit curve.

Improving Distribution by Grading: As shown by 9c and by Figs. 10 and 11, the summation of the currents (B-C) from or to the string are balanced above e, the point where the curve cuts the average line. If therefore we grade the units below e to bring the voltage of these units to near the average, then the upper part of curve will rotate to the right around e as center, or the curve above e will move horizontally to the right, due to stress taken from the lower units being added to the upper units, thus improving the entire string distribution. It is found this can be done very well by making the four lower units larger as so to give larger pins and adding to capacity by fixed shields around pins. This also reduces the leakage resistance stress on lower units.

Improving Distribution by Shielding: By raising the air potential opposite the lower units, the C currents may be increased and the B currents decreased. This improves distribution, but it also has effect of adding to air potential higher up and this increases the currents to the upper part of string, and the dry arcs tend to go to ground through the upper third of the insulator string. Note Figs. 28 and 29. Raising the line wire potential above the lower units is also objectionable for several practical reasons.

While not considered exact, the analysis does help us to understand the insulator problem.

Satisfactory voltage distribution may be obtained, as shown by Figs. 9, 10 and 11 and also by Figs. 12 and 13 and the distribution curves in the appendix:

1. By use of ring shield,
2. By use of insulated horn shield,
3. By grading the lower one-third of the units,
4. By combining pin-type insulators at line end with disk-type for the upper end of string.

Methods 1 and 2 are very similar and accomplish the result by control of the field, by reducing the B currents and increasing the C currents. (The B current refers to the current from metal parts of units to tower or ground and the C currents to the currents from line wire to metal parts of units, as shown in Figs. 9, 10 and 11). The disadvantage of raising the air potential above the units is that this also increases the C or line currents to the upper part of the string. And the dry arcs tend to break into the upper third of the string. (See Figs. 17 and 18.) By the use of the pin shields and line shield, the height of the ring or horn shield may be reduced and part of the objection to the shields removed.

By method 3 we keep the potential of the string as high as possible above the air potential, and hence tend to prevent the arcs from breaking into the string. By using four large diameter units, with larger pins to increase the electrostatic capacity at the line wire end, and by using the line shield, we get a very simple string. It is possible to use the four large units and a low ring or short insulated horn shield to further grade the lower two units, if desired. By this method the size and height of the shield as used in method 1 and 2 would be reduced, thereby making the shield less objectionable. The air potential gradient from line wire to tower should be made as flat as possible, as a steep gradient invites arcs. This means a long string; and the air potential due to the line wire should be as low as possible.

By method 4 the string potential is brought close to the air potential. This method is merely given here as a possible method, as it has not been worked out practically. No doubt other methods combining the present disk insulators with larger units at the line or with bushings or other types at the line end will be worked out.

Under wet conditions the potential distribution of the string improves materially. But the most important condition is the leakage distribution with dirty insulators as they become wet or dry.

Because of the large leakage surface and the low cost, and the conditions of the electric field in the upper two-thirds of the string, the present disk type of insulator meets the problem of the upper two-thirds of the string very well indeed.

I have no doubt the insulator men will work out a satisfactory solution for the insulators near the line wire, and *reduce the leakage resistance stresses* and *the air stresses* to less than one-half of those now prevailing on 110,000 to 175,000-volt lines. This is necessary in order to give a satisfactory operating string, in my opinion. Let all work to that end.

With the ungraded string the factor of safety is

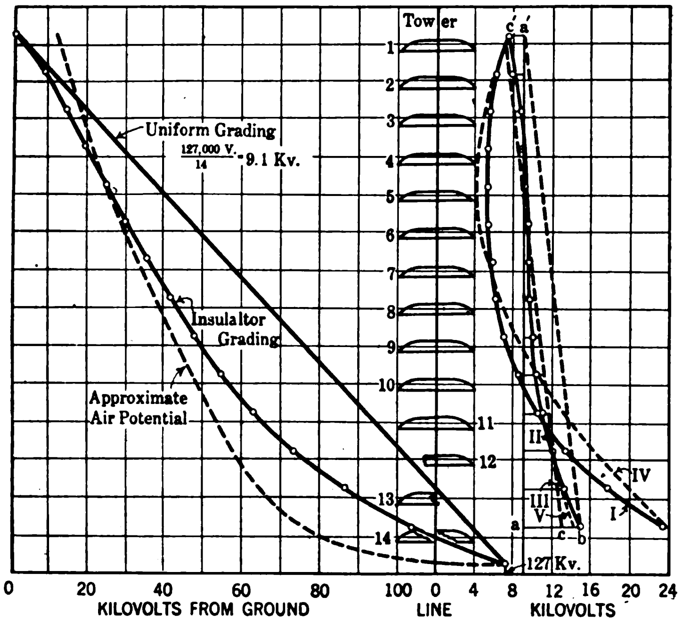


Fig. 10—Actual and Calculated Gradients—Cap and Pin Insulators—14-Unit String—127 kv.

Curve I. Actual gradient by test.
Curve II. $A + (B - C)$ from test.
Curve III. (Straight line). $A + (B - C)$ calculated by assuming $B = 6$, $C = 2$.
Curve IV. Gradient in kv. calculated from Curve III. $[A + \Sigma (B - C)]$.
Curve V. Extension of Curve II as it would be were there no disturbance of field due to lower pin and line wire.

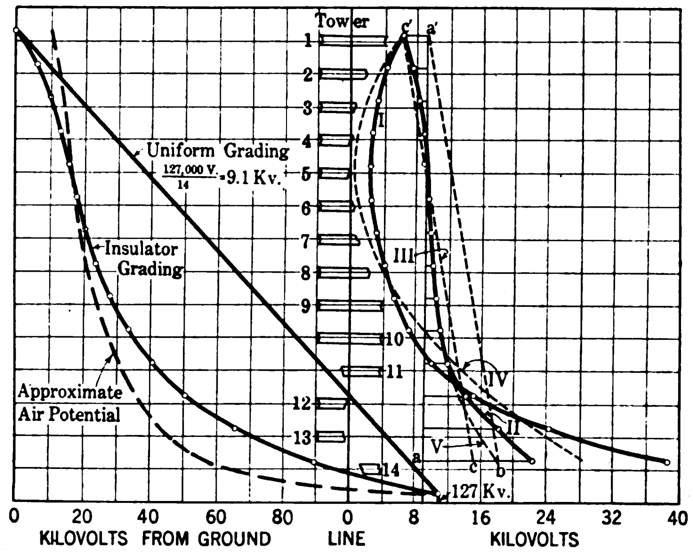


Fig. 11—Actual and Calculated Gradients—Hewlett Insulators—14-Unit String—127 Kilovolts

Curve I. Actual gradient by test.
Curve II. $A + (B - C)$ from test.
Curve III (Straight line). $A + (B - C)$ calculated by assuming $B = 9$, $C = 3$.
Curve IV. Gradient in kv. calculated from Curve III. $[A + \Sigma (B - C)]$.
Curve V. Extension of Curve II as it would be were there no disturbance of field due to lower pin and line wire.

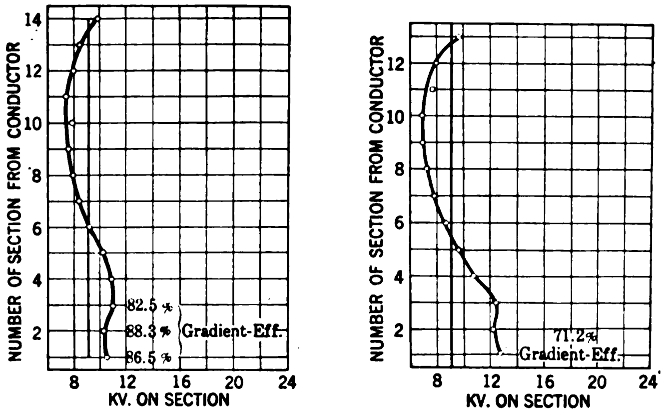


Fig. 12A—Voltage Distribution with Insulated Horn Shields and Line Shield

For 220-kv. line.
No. of sections in string—14.
No. of controls—4.
Size of controls—1 1/4 in. pipe.
Height of controls—9 in.
Spread of controls—23 in.
Angle with plane of conductor—45 deg.
Insulator on controls—No. 11623 spec.
Conductor shield—5—1-in. pipes spaced 60 deg. apart on 12-in. circle.

For 220-kv. line.
No. of sections in string—14.
No. of controls—2.
Size of controls—2 in.
Height of controls—8 1/2 in.
Spread of controls—23 in.
Angle with plane of conductor—90 deg.
Insulator on controls—No. 11623 spec.
Conductor shield—5—1-in. pipes spaced 60 deg. apart on 12-in. circle.

Tests by A. O. Austin

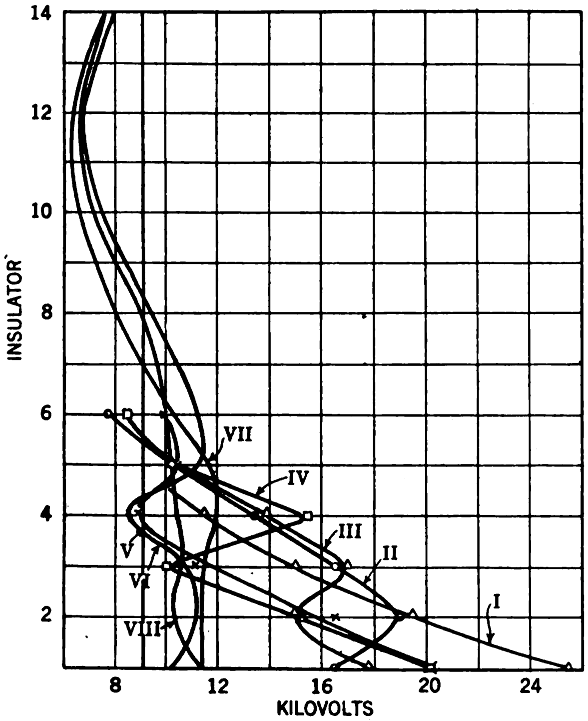


Fig. 12B—Cap and Pin-Type Units Graded for Voltage Distribution—Locke Insulators

Curve I. 14—No. 5800—10-in. cap and pin type. Ungraded.
Curve II. 1—12-in. special; 13—No. 5800. Ungraded. Corona shields on under side of 12-in. unit.
Curve III. 2—12-in. special; 12—No. 5800. Ungraded. Corona shields on 12-in.
Curve IV. 3—12-in. special; 11—No. 5800. Ungraded. Corona shields on 12-in.
Curve V. 4—12-in. special; 10—No. 5800. Ungraded. Corona shields on 12-in.
Curve VI. 4—12-in. special; 10—No. 5800. Graded by two 4-in. by 24-in. parallel tubes at third unit.
Curve VII. 14—No. 5800—10-in. cap and pin type. Graded by four oops of 3/4-in. pipe.
Curve VIII. 14—No. 5800—10-in. cap and pin type. Graded by 1 1/2-in. by 30-in. ring at center of third unit.
Tests by K. A. Hawley.

at the tower end instead of at the line wire end of the string. We should treat each insulator string as we have the end windings of transformers, not add more turns (or add more units), but increase the insulation or decrease the voltage stress on the units near the line wire, so that these can absorb the excess voltages due to switching etc., without undue stress. This can be accomplished by making the lower one-third of the units larger, with internal electrostatic capacity added to reduce the voltage, and by the use of a low external shield, which latter may be combined with a pin and line shield to reduce the stresses on the lower unit to satisfactory values.

4. The Leakage Resistance Gradient Over the Surface of the Insulator

In Fig. 14 is shown the theoretical resistance gradient for the standard insulator shown in Fig. 10, for the standard pin, and for 23,000 volts between cap and pin. It will be noticed that the resistance near the pin is very high and drops very rapidly in the first inch, due to the increase in the area of the leakage path. By enlarging the pin diameter we may reduce the maximum gradient near the pin very materially and increase the voltage gradient of the remainder of the insulator only a small amount as shown. The shaded area R 10 is equal to the sum of shaded areas $r_1 + r_2 + r_3$, etc. This result should be approximately realized if we short-circuit the part of the leakage resistance path near the pin as proposed by the use of the sleeve shield around the pin, as shown in Fig. 8.

Fig. 15 (data from tests by Prof. H. J. Ryan) is very interesting, showing that for the ungraded or unshielded unit we get actually a higher voltage at the edge of the disk than we do at the cap. This is no doubt due to the flux density near the line wire. We actually get 19,000 volts on the first inch of the leakage surface.

By short-circuiting to the first petticoat and putting a shield over the line wire, the voltage gradient is reduced one-half. By short-circuiting two petticoats we get a much better curve as shown by V and VI. Further study along this line is advisable.

The distribution of the resistance leakage stresses over the string and over each unit as uniformly as possible is, of course, the thing finally desired, and this is the main reason for striving for good string distribution of voltage. It is desired that the distribution remain as uniform as possible *for all conditions occuring in operation.*

5. Insulation of Switches, Transformers, Etc.

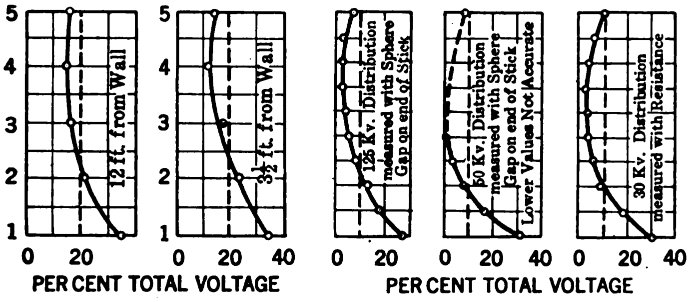
In the early days of electric power transmission the transformers, switches, etc., were housed to protect them from the elements. As the number of substations increased it was found often that the expense of housing the apparatus cost more than the apparatus. Hence there was developed outdoor apparatus.

The very large amount of space required for the 220,000-volt substation switches, etc., of course, makes it advisable to use outdoor apparatus so long as the total cost is less than where it is protected from the elements. Probably transformers and disconnecting switches can be more economically placed outdoors than in a building. But the oil switch may give a different conclusion on account of the fact that the enlargement of the bushings for the outdoor use also enlarges the tanks more than otherwise necessary, so that due to the increase in the bushing the cost of the switches for a given kv-a. capacity may vary somewhat as the square of the voltage, if all the elements of design are carried out consistently. That is, a switch for 220,000 volts may cost nearly double the cost of a switch for 150,000 volts due to the increase of the tank and oil, etc., as a result of the increase of the size of the bushing.

Now the size of the bushing is largely determined by the *wet* arc-over condition. A bushing for a 165,000-volt switch has a dry arc-over of about 480,000 to 520,000 volts. The wet arc-over of a 220,000-volt bushing will be around 400,000 to 450,000. (The wet arc-over for a 165,000-volt bushing is about 350,000 volts.)

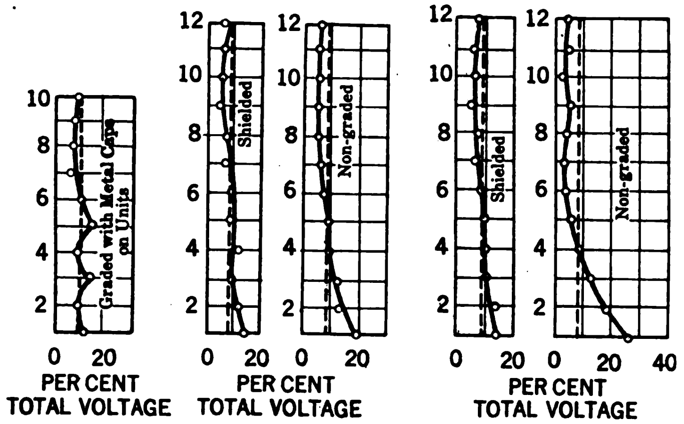
That is, by keeping the 165,000-volt switch, when used on the 220,000 lines, dry and clean, we have a greater factor of safety than we have for the 220,000-volt switch when used outdoors. And since the 165,-000-kv-a. switch will give all the rupturing capacity required, it will pay to use this type enclosed, if the cost of protecting it from the weather is less than the extra cost of the higher voltage switches. Of course all the above assumes that ample clearances are provided.

This point does not come up in the case of transformers



The effect of proximity to walls—voltage distribution on string of five insulators.

The effect of applied voltage on the distribution of a string of ten.



Voltage distribution on string of ten insulators.

Voltage distribution on string of twelve insulators.

Voltage distribution on two parallel strings of twelve insulators.

Fig. 13a—Distribution Curves for Hewlett Units

As per tests by F. W. Peek, Jr.

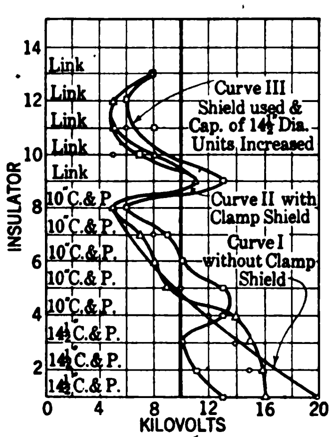


Fig. 13 b

Distribution Curve for Combination of Link & Cap & Pin Type Insulators

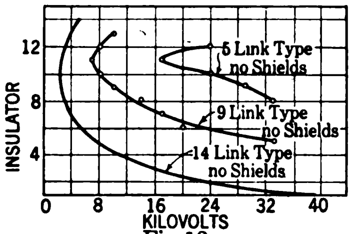


Fig. 13 c

Distribution Curves for Different String Lengths & Constant Voltage

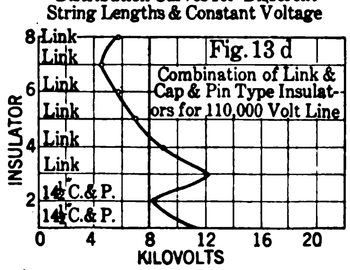


Fig. 13b-c-d

Tests by R. H. Marvin

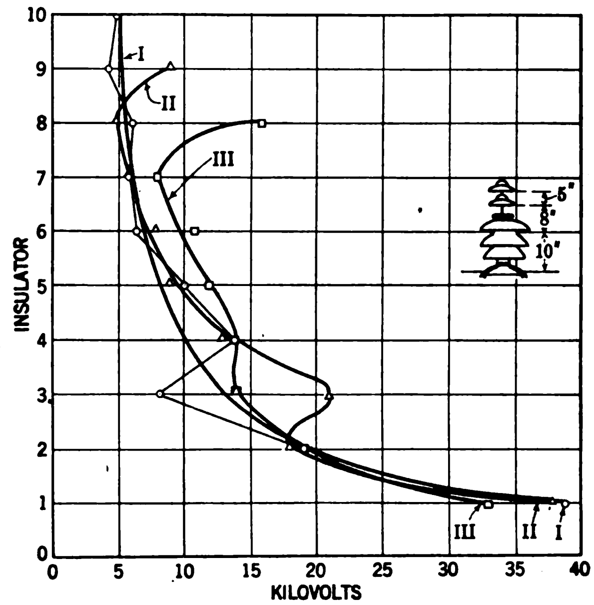


Fig. 13e—Distribution Curves for Link and Cap and Pin Type Combined with Pin Type to Make Insulator String Gradient Approximate Air Gradient

Curve I. One 14-in. special three-part Lapp pin-type insulator next to line and nine 10-in. Ohio Brass Co. cap and pin-type insulators between these and the tower. No shields.

Curve II. Two Thomas pin-type No. 13012 insulators next to line and seven link-type insulators between these and the tower. 6-in. by 3-ft. 0-in. cylindrical clamp shield.

Curve III. Thomas pin-type No. 13012 insulators at top and bottom with six Thomas cap and pin-type No. 1149 between. 6-in. by 3-ft. 0-in. cylindrical clamp shield.

127,000 volts duty on all three strings.

Tests by H. J. Ryan.

because the tanks are so large that the larger bushing cost is the only extra item to consider for the higher voltage. If the wet arc-over were increased by increasing the length and not the diameter, it would reduce the size of tanks, etc.

Especially in view of the present development of the art of high-tension switches, we should not expend more for switches than necessary at this time.

Hence, the protection of the oil switches from the weather should be given careful consideration. In this connection it may be noted that the wet 60-cycle arc-over for a 14-unit clean string of disk insulators will be about 450,000 to 550,000 volts, but of course, under outdoor conditions, due to dirt, etc., the arc-over voltage will be lower. We want the switches, of course, to have a higher factor of safety than the line units. Roof protection only may be sufficient.

6. Wet and Dry Arc-Over of Line Insulation

High-Frequency Arc. The control of the high-frequency arc can be effected as shown in Figs. 16 to 29. These tell their own story. The metal ring shield also gives satisfactory high-frequency arc control. That we need not worry about high-frequency arcs is shown by these illustrations, Figs. 18-21.

60-Cycle Dry and Wet Arc-over. The dry arc-over voltage for a 14-unit string of insulators, shielded with ring or insulated horn shields, is about 700,000 volts, or 50,000 volts per unit. The arc clears the insulators fairly well, but sometimes breaks into the upper third of the string.

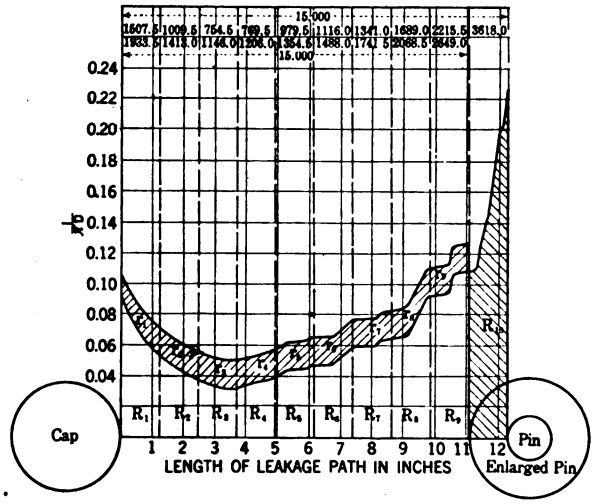


Fig. 14—Calculated Resistance Gradient and Method of Reducing Maximum Gradient

Surface resistance integral curves for Ohio Brass Co. Insulator No. 25620.
Area R_{10} = Area $r_1 + r_2 + r_3 \ldots\ldots + r_9$.
See Fig. 8 for leakage path measurements.

Under wet test the arc tends to follow along the string of insulators and the wet arc-over voltage is about 60 per cent of the dry arc-over value, or about 450,000 to 550,000 volts for 14 units, with precipitation of 0.2 in. per minute. The wet arc-over as well as the dry arc-over is affected by the string impedance and especially by the impedance of the upper two-thirds of the string.

The control of the wet arc, to keep it away from the string of insulators, is important. The following tests were made to show that the arc can be controlled in direction and kept away from the string. Fig. 24 shows the arc-over controlled so as to go to the lower crossarm. This is done by hanging two insulator units properly spaced below the line wire and then adjusting a pointer on the lower arm to direct the arc. The theory is that the units below the line will become dirty and wet and the insulation depreciate as do the line units. The adjustment for the wet and dry arc to travel to the lower arm can be very close to the arc-over for the string. Instead of hanging the

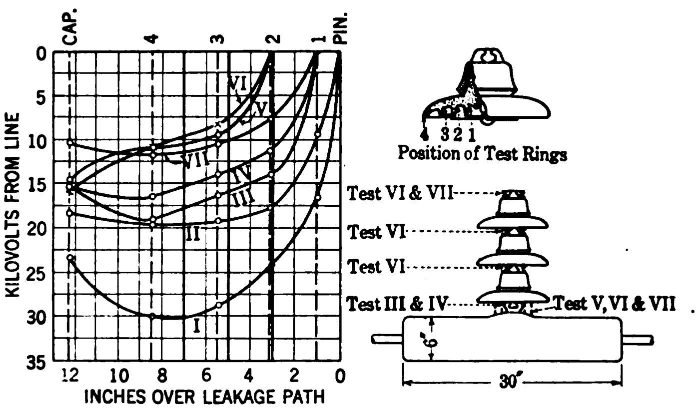


Fig. 15—Voltage Distribution over Insulator Surface

Ohio Brass Co. Insulator No. 25620.

CONDITIONS:
Voltage duty over insulator string, 127 kv. to ground. 3/4-in. iron pipe used as line conductor. Standard clamp and hardware.

TEST I:
String of 14 units of O. B. insulators. Test on bottom unit. Rings of No. 14 B. & S. copper fastened with wax in positions shown. No control shields on string.

TEST II:
String of 14 units of O. B. insulators. Test on bottom unit.
Rings of No. 14 B. & S. copper as above.
6-in. diameter iron cylinder, 30 in. long, placed over conductor and extending along conductor 15 in. each side of insulator. Ends of cylinder rounded in.

TEST III:
String of 14 units of O. B. insulators. Test on bottom unit.
Rings each replaced by two arcs of 1/4 circumference. Bisecting radius of arcs at right angles to line. 6-in. diameter cylinder as in II. Sheet iron cylinder around insulator pin between 6-in. cylinder and insulator to increase pin diameter out to position 1.

TEST IV:
Same as III, except bisecting radius of wire arcs parallel to line.

TEST V:
String of 15 units of O. B. insulators. Test on bottom unit.
Rings of No. 14 B. & S. copper fastened in positions shown. 6-in. diameter cylinder as in II. Sheet iron cylinder around insulator pin between 6-in. cylinder and insulator to increase pin diameter out to position 2.

TEST VI:
Four Hewlett insulators at top of string. Five O. B. insulators next. Four O. B. insulators with cylinder surrounding pin and in contact with cap below to give pin diameter out to position No. 1. Bottom unit as in Test V. Pin diameter to position 2 and 6-in. by 30-in. long cylinder around conductor.

TEST VII:
String of 14 O. B. insulators. Test on fourth unit from bottom. Bottom unit as in III except arcs replaced with rings of No. 14 B. & S. copper. Sheet iron cylinder surrounding pin of fourth unit and in contact with cap of third unit to give pin diameter out to position 1.

Tests by H. J. Ryan.

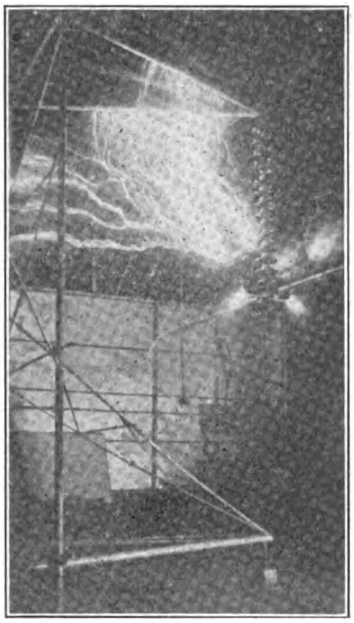


Fig. 16—High-Frequency Arcs with 4-in. by 24-in. Horizontal Shields

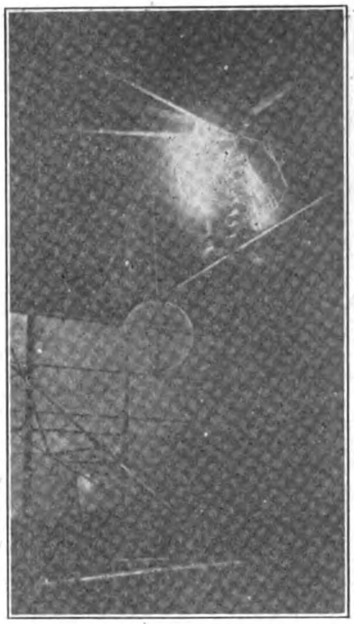


Fig. 17—High-Frequency Arcs with 4-in. by 12-in. Vertical Shields

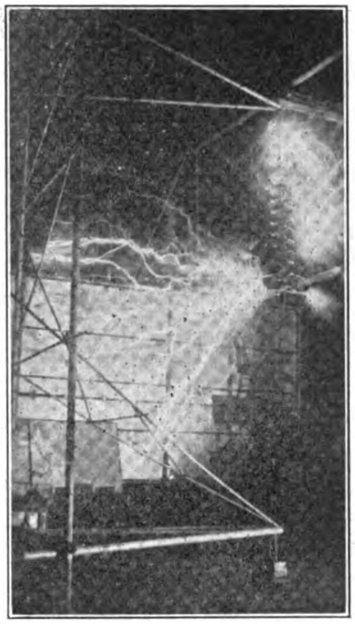


Fig. 18—High-Frequency Arcs with 2-in. by 12-in. Vertical Shields with Insulator over Shield on Tower Side

All tests made at Stanford University, Feb. 3, 1921.

extra units from the line wire, we may hang them from the lower arm, about two feet towards the tower from the line insulators. The wet and dry arc can by proper adjustment be made to clear the string. Instead of the insulators hung from the arm, we may hang a porcelain tube to direct the arc. The result here is even more satisfactory than for the other two cases above. Test Sheets 1 to 4 in the appendix show the result of tests of various methods of arc control.

While the wet and dry arcs may be controlled as above, it is believed this control should be used only as a final protection in certain places. *The effort should be to eliminate the arcs entirely* and it is believed this can be accomplished, except for cases of accident.

Suppression of Incipient Corona or Arcs. I am confident from all my observations and studies that the final complete success of power transmission, at voltages higher than can be handled by pin-type insulators, must come from the design of the metal fixtures (including the line wire) in contact with the air and porcelain, so that the air gradient and leakage gradient will be reduced to low values, in order that there be no tendency for arcs to start, and the maximum unit and leakage resistance will also be reduced to low values. Corona should also be prevented on account of the formation of acids.

Only a small part of the tests made have been included in this paper, in order to keep it within reasonable length. The manufacturers and engineers have heartily cooperated in the tests, and I hope to see cooperation in manufacture to bring about confidence in the transmission industry as a whole.

Conclusion

The insulator problem of the transmission line must be attacked as any other engineering problem. The attempt here made to give the results of work along this line will, it is hoped, encourage further study by engineers and manufacturers.

The insulation problem, as does every engineering problem, reduces itself to working to certain unit stresses—mechanical and electrical—and to the maintenance of certain factors of safety throughout the entire line structure, which includes insulators, towers,

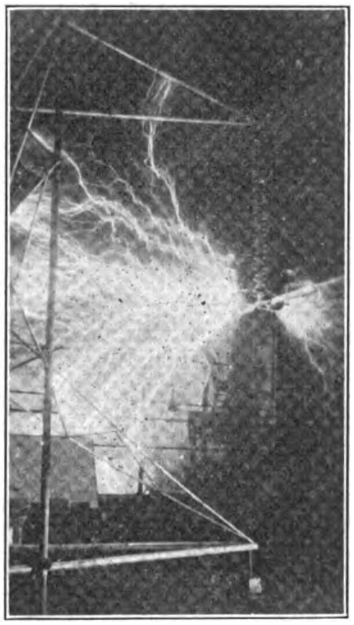


Fig. 19—High-Frequency Arcs with 2-in. by 12-in. Vertical Shields with Insulators over Both Shields

All tests made at Stanford University, Feb. 3, 1921.

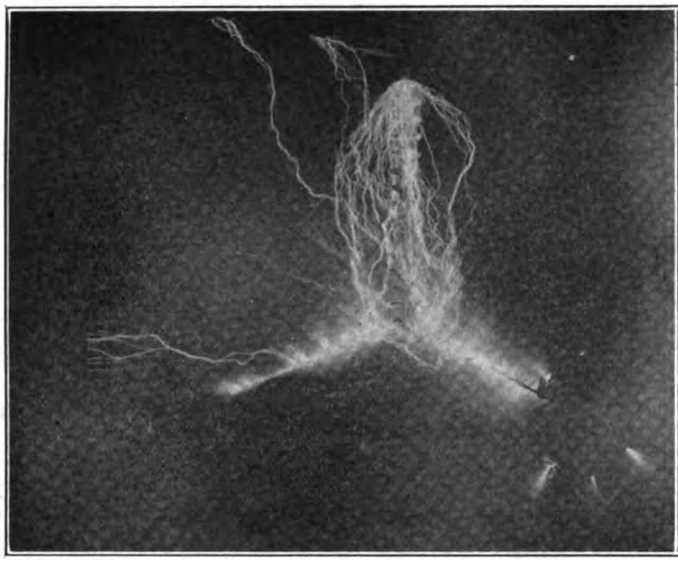


FIG. 20—TEST WITH 500,000-CIR. MIL, P. G. & E. CONDUCTOR, 14-UNIT STRING, No. 25620

Approximately 545 KV., 35,000 cycles.

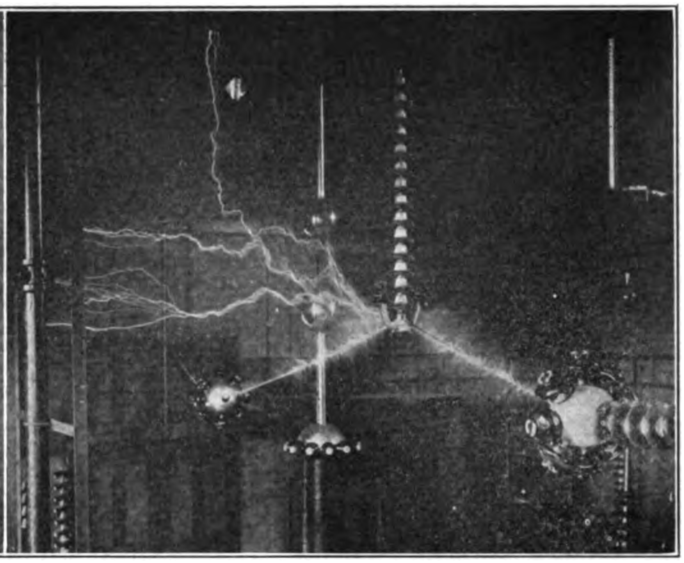


FIG. 21—INSULATOR No. 11622 ON CONTROLS AT 45 DEG.

Approximately 545 KV., 35,000 cycles. Compare with Fig. 20.

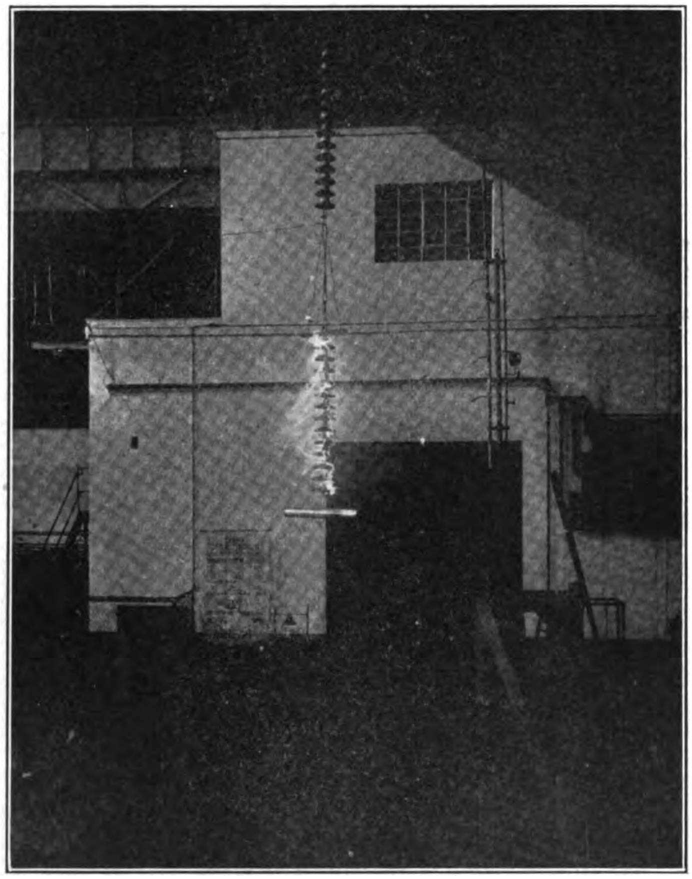


FIG. 22—WET ARC-OVER—CITY WATER—THREE-LINE UNITS WITH INTERNAL SHIELDS TO INCREASE ELECTROSTATIC CAPACITY

Wet 60 ~ arc-over at 505 KV. on a string of 13 cap and pin units, graded.
Ten Locke No. 5800 units at tower end; three 12-in. disk units at line end.
5-in. diam. tube, 4 1/2 ft. long, around the line conductor.
Precipitation—0.2 in. per min.
Tests at Pittsfield, Mass., April 15, 1921.

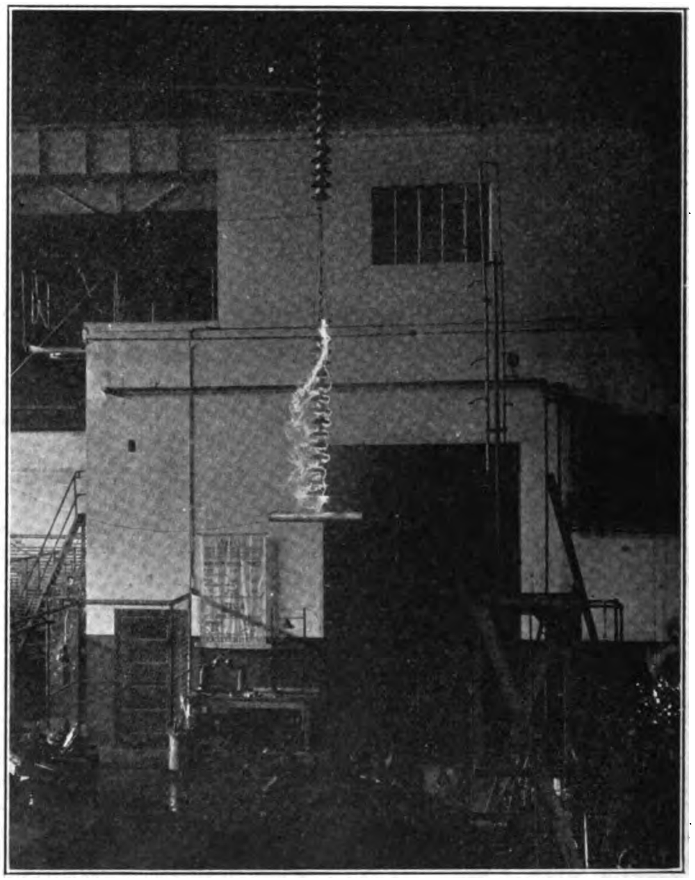


FIG. 23—WET ARC-OVER—CITY WATER—THREE-LINE UNITS WITH INTERNAL SHIELDS TO INCREASE ELECTROSTATIC CAPACITY

Wet 60 ~ arc-over at 546 kv. on a string of 14 cap and pin units, graded.
Eleven Locke No. 5800 units at tower end; three 12-in. disks at line end
5-in. diam. tube, 4 1/2 ft. long, around the line conductor.
Precipitation—0.2 in. per min.
Tests at Pittsfield, Mass., April 15, 1921.

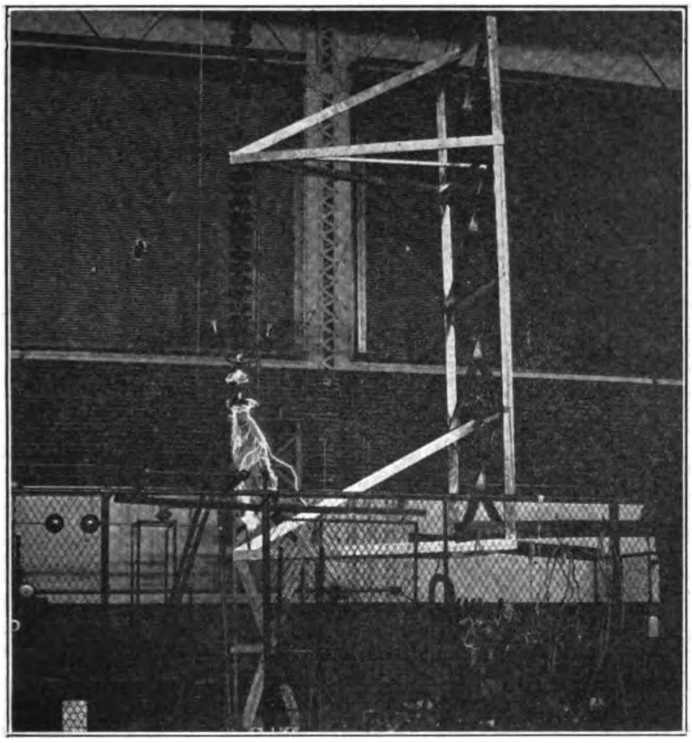


Fig. 24—Wet Arc-Over, 467 kv.—14 Hewlet Units—Precipitation 0.2 in. per Minute—Using Two Insulators below Line Wire to Direct Arc

Tests at Pittsfield, Mass.

switches, transformers, etc. This factor of safety should be as permanent as possible, which means that the depreciation of the insulator should be practically nil in service. This goal is being rapidly reached.

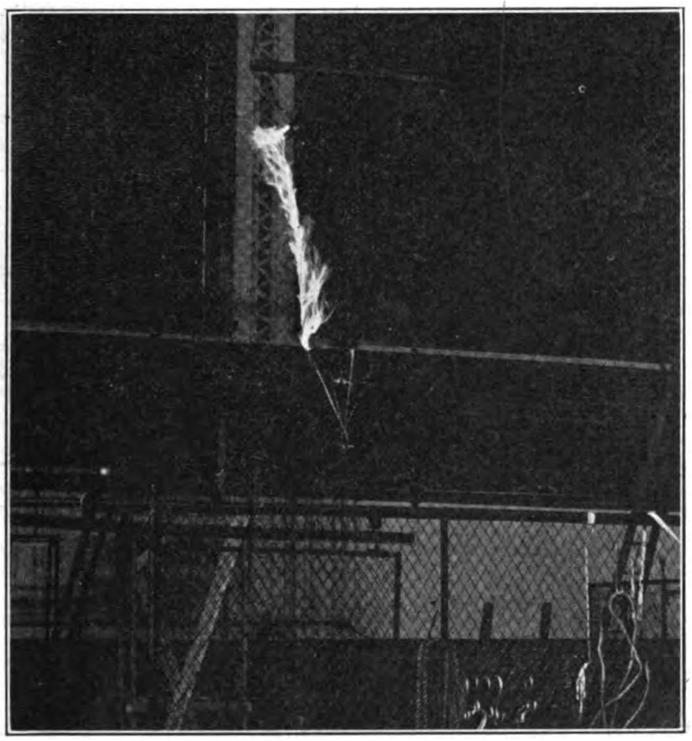


Fig. 25—Wet Arc-Over for Arrangement Shown, 508 kv. Dry Arc-Over, 728 kv.

Tests at Pittsfield, Mass.

It is shown that satisfactory voltage distribution at normal voltage may be obtained by different methods of shielding or by different methods of grading. Further work along this line is desirable in order to crystallize the best methods into practical forms, so that the insulator manufacturers will be able to furnish the complete line insulation equipment.

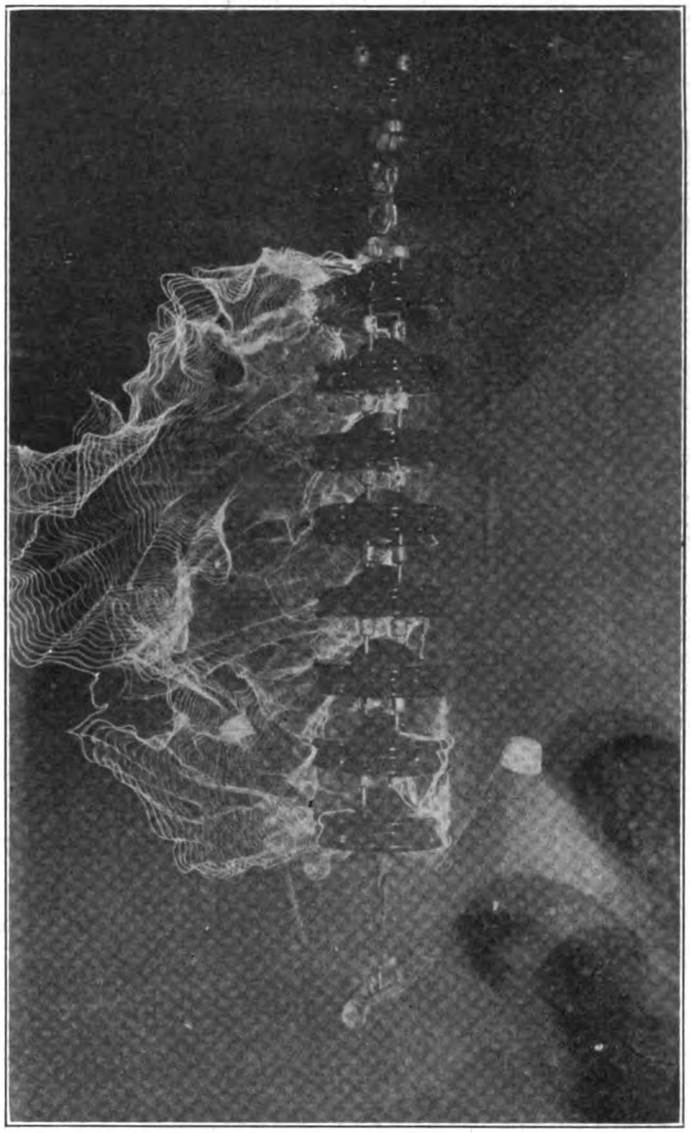


Fig. 26—Tests on No. 1054 Insulator—Without Tinfoil Caps

Wet flash-over, 331 kv.
Spacing, 5 1/2 in.
Dry flash-over for same 8 units, 380 kv.
Tests, R. Thomas & Sons.

It is believed that 220,000-volt transmission is no more difficult than 110,000 or 175,000, if due consideration is given to the unit air and leakage resistance stresses, and the insulation of the line is carried out consistently, as is, for example, the track system of our best railways. But this means, of course, that we must not have on a main-line track 120-lb. rail and 60-lb. rail over which high-speed trains run. The factor of safety in the insulated string should be at the

line wire end so that shocks may be absorbed without undue stress on these units.

Double-string and dead-end insulator strings should be avoided wherever possible, and in place of these, extra strength units should be used, to allow insulators to swing clear at angles as far as possible.

Higher voltages than 220,000 are possible, but for practical reasons, as given in Part I, it is believed

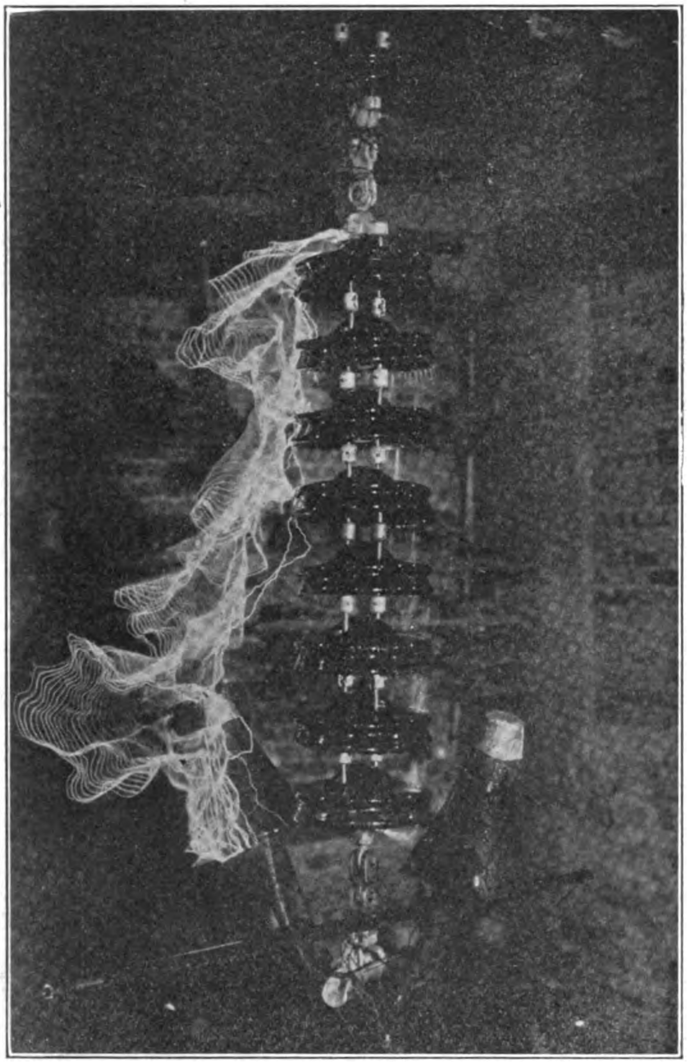


FIG. 27—TESTS ON NO. 1054 INSULATOR—TINFOIL CAPS ON HORN INSULATORS

Wet flash-over, 331 kv.
Spacing, 5 1/2 in.
Dry flash-over for same 8 units, 380 kv.
Tests, R. Thomas & Sons.

220,000 should be standard for extra large-power, long-distance transmission. Heretofore I have always said we would go to higher voltages, because we had not reached the voltage required for extra large blocks of power and long distances. I believe 220,000 volts is high enough to meet any situation in this country today.

It is the peculiar characteristic of nearly all electrical apparatus that it depreciates less when used in normal service than when taken out of service for part of each day.

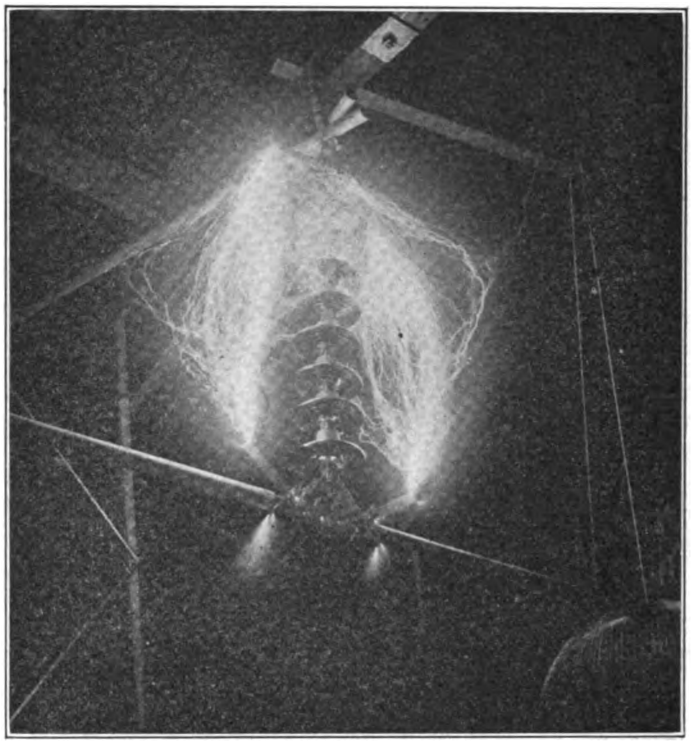


FIG. 28—NINE UNITS—30 FLASH-OVERS—10 CLEAR AND 20 CASCADE

Note bowing out of flux lines at lower end and break-down to upper part of string where string potential is low.
This figure and Fig. 29 illustrate that we must increase string potential in the upper third and decrease the air potential due to the line wire.
Figs. 28 and 29 by Prof. H. J. Ryan.

This is because the depreciation depends largely on the maximum range of temperature changes and the number of such changes or cycles in a given period. All electrical apparatus, including transmission lines,

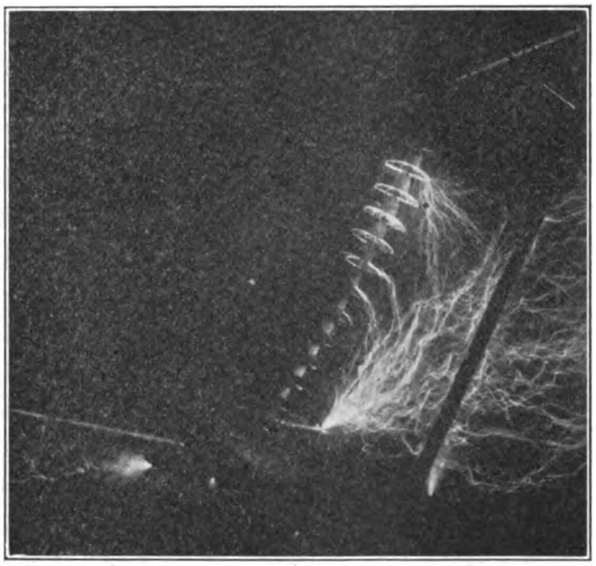


FIG. 29—TWELVE UNITS—30 FLASH-OVERS

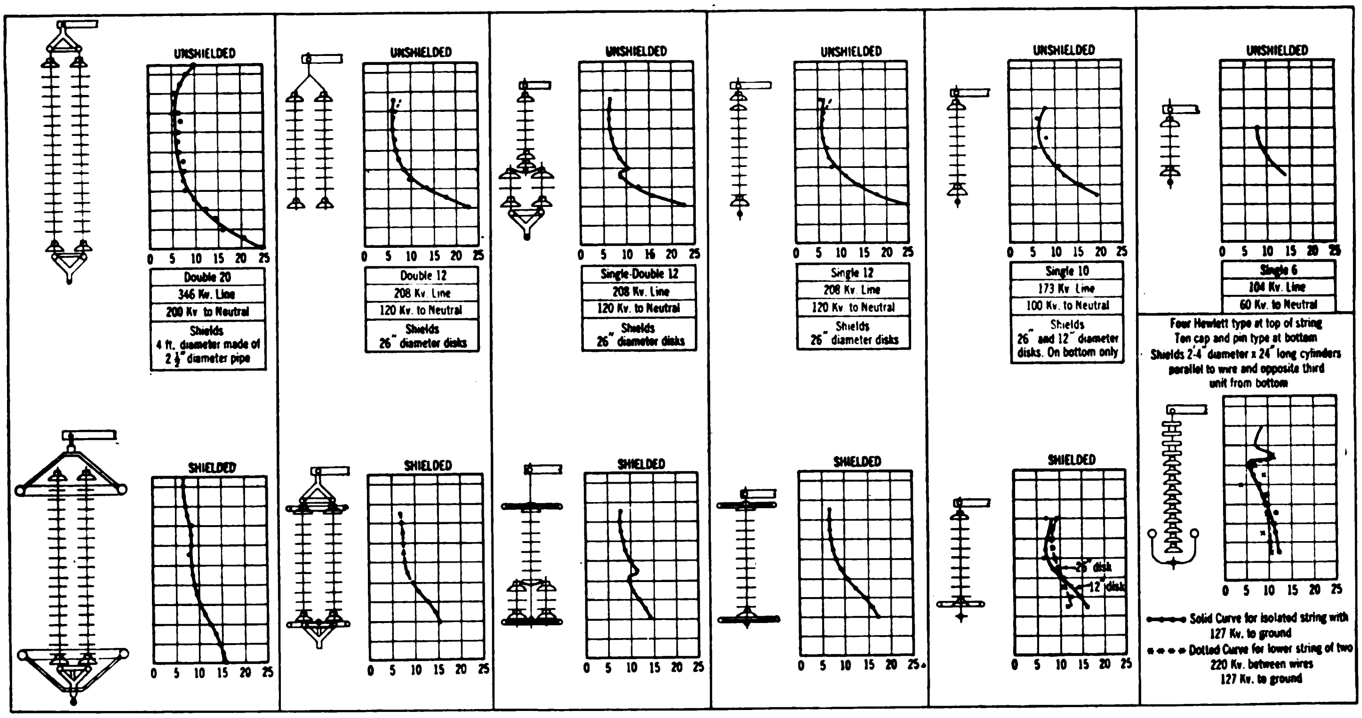
Note bowing out of flux lines at line end due to high string potential and break-down to upper units due to high air potential and low string potential.
This figure and Fig. 28 illustrate that we must increase string potential in the upper third and decrease the air potential due to the line wire.
Figs. 28 and 29 by Prof. H. J. Ryan.

should be in constant service under conditions that will as nearly as possible cause the apparatus to remain in one condition. It is believed transmission lines will give better service when voltage is maintained on them at all times.

A system of transmission controlled as to voltage as given in Part I, and insulated consistently by one of the methods given in Part II, to give low air and resistance leakage stresses at all voltages and under all conditions, will give service not possible on lines where these conditions are not carried out. I hope to see a real era of 220,000-volt transmission construction in the next few years, and the engineers and manufacturers can help matters along by proper cooperation.

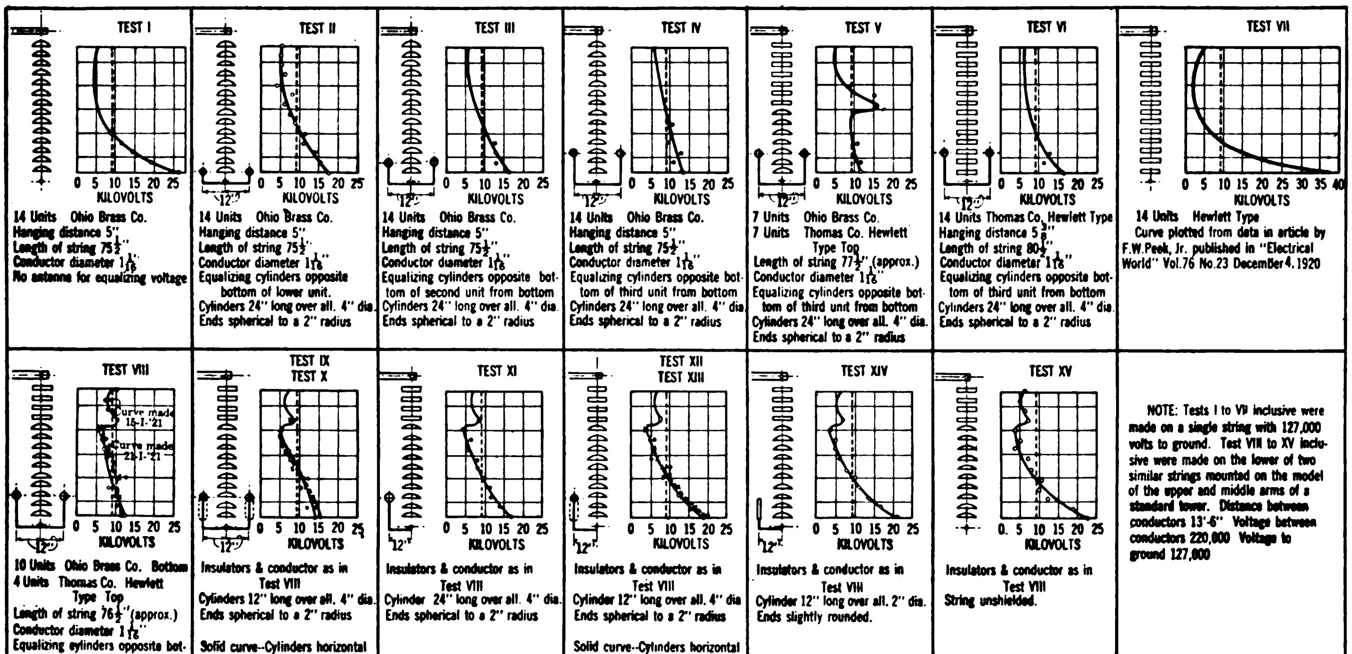
APPENDIX

Tests of Voltage Distribution   Tests of Arc-Over Voltage, etc.

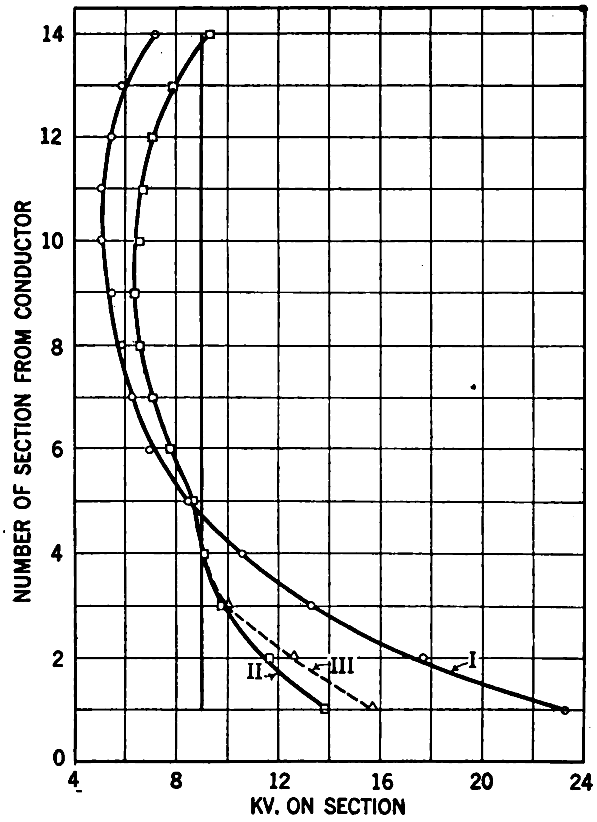


DISTRIBUTION SHEET D1—VOLTAGE DISTRIBUTION FOR CAP AND PIN-TYPE INSULATORS, SINGLE AND DOUBLE STRINGS WITH AND WITHOUT SHIELDS

From data as determined by Harris J. Ryan and Henry H. Henline, JOURNAL of A. I. E. E. July, 1920.

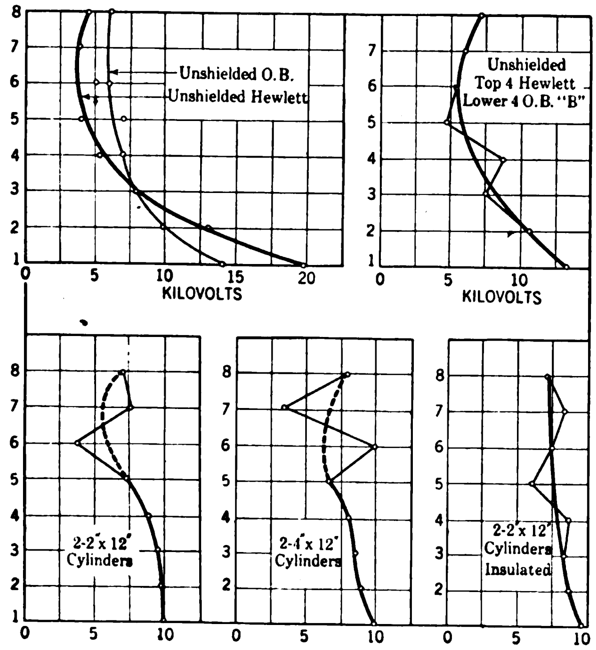


DISTRIBUTION SHEET D2—IMPROVING DISTRIBUTION BY CYLINDRICAL OR HORIZONTAL SHIELDS OR BY COMBINATION OF INSULATORS **14-Unit insulator strings, 220-kv. transmission line.** **Tests by H. J. Ryan.**



DISTRIBUTION SHEET D3—SHOWING EFFECT OF SIZE AND PLACING OF SHIELDS ON VOLTAGE DISTRIBUTION

Potential Gradient for Ohio Brass Co. Insulator No. 25620.
14 Units in string for 220-kv. line.
Curve I. Unshielded string.
Curve II. Number of controls—2.
Size of controls—2-in. pipe.
Spread of controls—30 in.
Height of controls from conductor—20 in.
Angle with plane of conductor—90 deg.
Insulator on controls—special 125523.
Curve III. Same as Curve II except angle of controls with plane of conductor changed to 30 deg.
Date of tests—March 3, 1921.



DISTRIBUTION SHEET D4—DISTRIBUTION CURVES FOR EIGHT UNITS

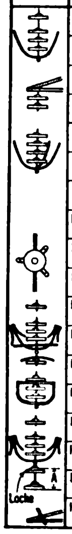


Diagram	Type Insulator	No. Units	Type Shield	Arc-Over Dry	Arc-Over Wet	Max V. Dist. %	Character of Arc
	Hewlett 10	14	None	Kv. 750	Kv.		Arcing to Top Cascade
	Hewlett 10"	14	2 Horns Uninsulated	595			Arcing to Top with tendency to strike in
	Hewlett 10"	14	2 Horns Insulated	705 698			All Arcing clear to Top Arc to Horn 7" below Line
	Hewlett 10"	14	3 Horns Uninsulated	606			Arc from Horns to Top Arc strikes in
	Hewlett 10"	14	3 Horns Insulated	700 684			Cascade to Top
	Locke 12"	14	3 Horns Uninsulated	557			Cascade to Top
	Locke 12"	14	3 Horns Insulated	612			One Arc to Tower Four Cascade to Top
	Locke 10"	14	3 Horns Uninsulated	581			All Arcs clear to Top
	Locke 10"	14	3 Horns Insulated	640			Arcs tend to Cascade
	Locke 10"	14	3 Horns Uninsulated	567 574			Arcs strike in
	Locke 10"	14	3 Horns Insulated	631			All Arcs clear to Top
	Hewlett 10"	14	2 Insulated Horns with Arcing Tips	698			Arcing from outside Horn clear to Top
	Hewlett 10"	14	2 Insulated Horns with Arcing Tips	674			Arc to Tower Tower 6" closer than above
	Hewlett 10"	14	Circular Shield Arcing Horn on Top Unit	663			Arc clear to Horns
	Hewlett 10"	14	Circular Shield no Arcing Horn	697	455		Arcs clear to Top
	Hewlett 10"	14	2 Insulated Horns 2 Units below A = 12"		431		All Arcs to Horn Horn distance to Line 69" to Lower Insulator 39"
	Hewlett 10"	14	2 Insulated Horns 4 Units below Line		463		All Arcs clear to Top Horn distance to Line 69" to Lower Insul 39"
	Hewlett 10"	14	2 Insulated Horns 3 Units below Line		458 454		Arcs Clear to Top Horn distance to Insul 55" Arcs Clear to Top Horn distance to Insul 44"
	Hewlett 10"	14	2 Insulated Horns 6 Units below Center 4 Shorted	497	437		All Arcs to Horn Horn distance to Line 81" to Lower Insulator 39"

TEST SHEET 1

Tests made at Pittsfield, Mass.

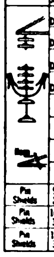
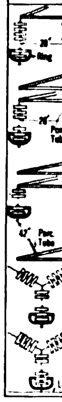


Diagram	Type Insul below line	No. units	Horn to Lower Ins.	Arc over Dry	Arc over Wet	% Distribution 1 2 3 4 5 6	Character of Arc
	3 Locke Double Space	14	2' 10"	Kv. 420		[illegible]	No horn on lower arm Arc from lower arm to bottom unit and cascade
	3 Locke Double space	14	3'-6"	434			No horn Arc as above
	2 Hewlett Double space	14	4'-5"	540			No horn Arc to center of lower unit
	2 Hewlett Double space	14	4'-4½"	526	467		Dry Arc from horn to low unit Wet Arc from horn to line
	3 Hewlett Double space	14				[illegible]	
	No units below line	14				[illegible]	
	One Locke unit	8	3'-0"	292			Arc to upper arm
	One Locke unit	8	2'-6"	277			Arc to horn on lower arm
Pin Shields	9 Locke 10" 3 Locke 12"	12			479		
Pin Shields	10 Locke 10" 3 Locke 12"	13			505		
Pin Shields	11 Locke 10" 3 Locke 12"	14			546		

TEST SHEET 2

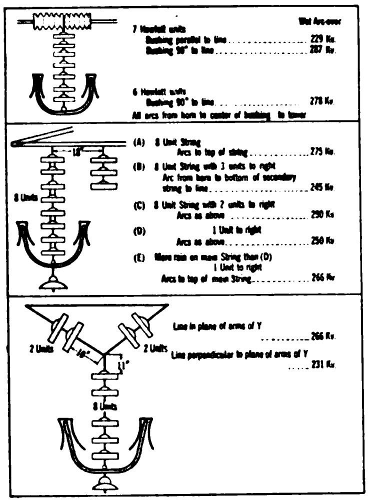
Horn shielding.
Arc-over on Hewlett Strings.
Horizontal distance from tower:
14 units—9 ft.
8 units—5 ft.
Tower No. 2 (Multi-member).
Tests made at Pittsfield, Mass.



Diagrams	No. of Units	Remarks	Arc-over Dry	Arc-over Wet	Character of Arc
	14	Por. Aux. 2 unit String opp. 1st & 4th units Strings 28" center to center		476	Arcs along drip on main string
	14	2" Porc. tube 53" long par. to main string 28" from center line of string		423	Dry Clears to brace at 621 Wet Arcs to tube clear of string Very good
	14	2" Porc. tube 27" long on brace 42" from line		480	Dry Arcs to brace at 571 string & tower damp Wet Arcs to tube Clears O.K.
	10	10 units in main string 4 units in each short string	728	513	Dry Arc clears string Wet Starts along drip & bows out
	10	10 units in main string 4 units in each short string	687	512	Dry Arc clears insulator surface damp Wet Arcs along drip to common point

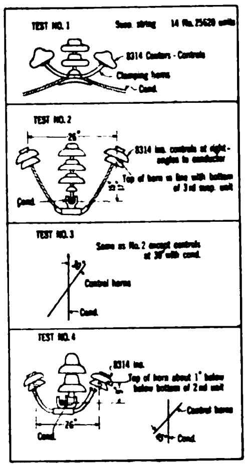
TEST SHEET 3

Ring shielding.
Arc-over on Hewlett strings.
Horizontal distance from tower, 9 ft.
Tower No. 2 (Multi-member).
Tests made at Pittsfield, Mass.



Test Sheet 4

Tests made at Lisbon, Ohio.



Test Sheet 5 —Oscillator Test Data

Ohio Insulator Company.

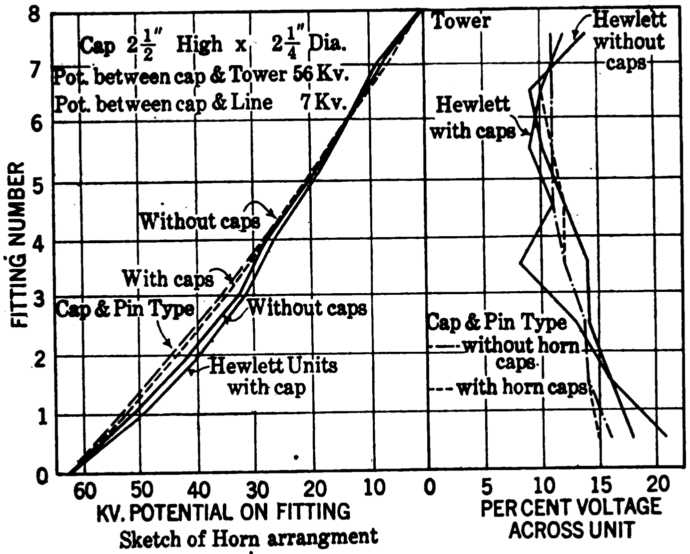
TEST SHEET 6. (OHIO INSULATOR CO.) FLASH-OVER TESTS

March 3, 1921

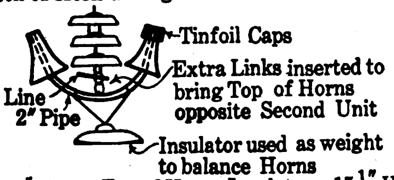
Time	V. M. Read.	Multi.	Volts Prim.	Kv.			Water	lb.
					8 units 25620, with 11622 as control on 1-in. pipe horns.			
2:58	113 (?)	4			flash-over	Photo No. 11	Tap	38
3:00	104.5	4	418	245	" "		"	"
3:01	102.	4	408	239	" "		"	"
					Horns changed to 22 in. spread.			
3:45	105.5	4	422	247	flash-over	Photo No. 12	"	"
3:48	105	4	420	246	" "	" No. 14	"	"
					No horns—No controls.			
3:56	110.5	4	442	259	flash-over	Photo No. 17	"	"
					12552 center as control 22 in. spread.			
4:15	70	4	280		No flash-over		"	"

—Ratio used on Leakage Test—

No. 3 Trans. ratio = 585
No. 4 Trans. used as C. T. ratio = 0.000903
C. T. No. 369 (48 turns) Ratio = 5
Total C. T. ratio = 0.000903 × 5 = 0.004515
Wattmeter Ratio = 0.004515 × 585 × Instru. Multi.
= 2.64 × Instrument Multi.
Wattmeter Fields in series, 150-v. circuit. Both sides × ¼.



Sketch of Horn arrangment



Line to 1st. unit 7", Line to Top of Horn Insulators $15\frac{1}{2}''$, Horns Spread $26\frac{1}{2}''$

Test Sheet 4b—Comparison of Insulated Horn Shields With and Without Tinfoil Caps

8 HEWLETT UNITS

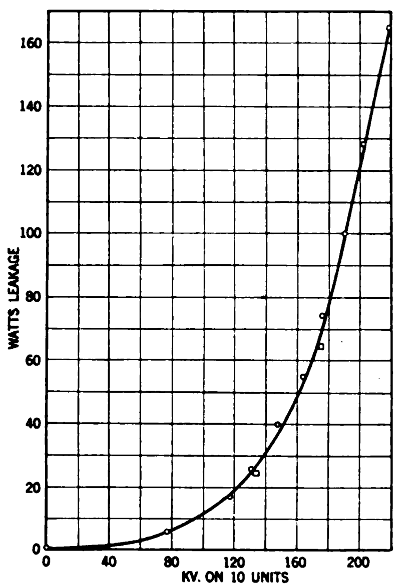
1. Dry arc-over without caps on horn insulators.............401 kv.
   373 "
   401 "
   (All arcs from horn to top clear of string.)
2. Dry arc-over with tinfoil caps
   378 "
   380 "
   (Arced clear of string from horn to top)
7. Wet arc-over without tinfoil caps
   329 kv.
   331 "
   (Arced from horn to top of string.)
8. Wet arc-over with tinfoil caps
   331 kv.
   327 "
   (Arced from horn to cap to top of string.)

CAP AND PIN-TYPE INSULATOR

Line to first unit......... 6½ in.
Line to top of horn.....15½

4. Dry arc-over without tinfoil caps
   1st trial.............406 kv.
   2nd trial..Did not arc over at 429 kv. (limit)
3. Dry arc-over with tinfoil caps
   408 kv.
   397 "
   (Arced from horn to cap to top of string.)
6. Wet arc-over without tinfoil caps
   289 kv.
   289 "
   (Arced along string.)
5. Wet arc-over with tinfoil caps
   331 kv.
   313 "
   (Arced from horn to cap to 5th unit to top.)

Tests at Lisbon, Ohio



Test Sheet No. 7—Leakage Wet Test

Precipitation, 0.2 in. per min.
10 units, No. 25620, with No. 12252 shells as controls.
Ohio Insulator Co.

TEST SHEET 8—(OHIO INSULATOR CO.)
OSCILLATOR TEST DATA

Date March 2, 1921

Time	Gen. volts	Gen. amps.	Primary turns number	Primary turns spacing	Primary capacity mfd.	No. of secondary turns	Sphere gap setting	Size of spheres	Kv.	Secondary current milliamp.	Wave-meter setting	Coil no.	Freq.	Water and lb. pressure	Remarks: Photo no.	Remarks: Time	Remarks: Exp.
						See test sheet No. 5 for description of set up.											
Test No. 1																	
10:31	520	155	10	2¼"	0.3813	16200	20"	50 cm.	545					Dry	13	1 min	32
Test No. 2																	
12:0	520	160	"	"	0.3813	"	20"	"	545					"	1	1 min.	32
12:06	520	160	"	"	"	"	20"	"	545					"	2	30 sec.	32
Test No. 3																	
12:10	520	150	"	"	"	"	20"	Gap	did not	arc.				"	5	1 min.	32
12:14	520	150	"	"	"	"	"	50 cm.	545					"	6	7 sec.	32
Test No. 4																	
1:29	500	145	"	"	"	"	20"	No arc.		1.70 to 1.75				"	7	15 sec.	32
1:31	500	145	"	"	"	"	"	"	"	1.70				"	8	1 min.	32
1:45	500	145	"	"	"	"	"	"	"	—No lights on—				"	9	10 sec.	32
Test No. 5	(Like	No. 4		except	10 deg.)												
1:52	..	..	10	2¼	0.3813	16200	20"	No arc.		1.72	145	2	35,000		Freq. Reading		
1:56	500	155	"	"	"	"	"	"	"	1.8				"	10	..	32
Test No. 6	(Like No. 4 except no horns or controls)																
2:04	520	150	10	"	"	"	20	No arc.		1.73				"	11	45 sec.	32
2:10	390	92	10	"	"	"	5½	50 cm.	250	1.2				"			
							4½	"	211	considerable corona on cond.							
2:20	..	..	"	"	"	"	4	"	190	0.9	little corona on cond.						
..	..	..	"	"	"	"	3½	"	167	..	corona starting						

TEST SHEET 9. (OHIO INSULATOR CO.)
LEAKAGE TESTS

March 3, 1921

Time	V. M. read.	Multi.	Volts prim.	Kv.	Amp. meter	Act. amp.	W. M. conn.	W. M. multi.	W. M. ratio	W. M. read.	Act. watts.		Water lb.
				10 units.	No. 25620.	With 12252 shell as control.							
12:45	76	2	152	78	0.12	0.00055	S–150	¼	0.66	8	5.3	Std.	38
	100	2	200	117	0.16	0.00073	"	"	"	26	17.	Water	"
	112	2	224	131	0.19	0.00086	"	"	"	40	26	"	"
	126	2	252	148	0.215	0.00098	"	"	"	60	40	"	"
	138.5	2	277	162	0.245	0.00110	"	"	"	84	55	"	"
	75	4	300	176	0.276	0.00125	"	"	"	112	74	"	"
12:50	81	4	324	190	0.31	0.00140	"	"	"	151	100	"	"
12:50 +	86.3	4	345	202	0.338	0.00153	"	"	"	194	128	"	"
12:51	93.5	4	374	219	0.383	0.00172	"	"	"	250	165	"	"
1:38	114.5	2	229	134	....				0.64	38	25	Tap	"
1:38 +	147.5	2	295	173	0.26				"	98	65	Water	"
1:40	125	4	500	292	10 units would not flash							"	"
1:50	107	4	428	250	8 units flash-over one control punct.								
1:54	110½	4	442	258	8 units flash-over.							"	"
1:55	110½	4	442	258	" " "							"	"
			8 units with 25978 Post ins. as controls										
2:05	73	4	292	171	flash-over							"	"
2:06	69	4	276	162	" "							"	"
			8 units, with 12252 shell & center as control with 1" pipe horns.										
2:37	116	4	464	272	flash-over							"	"
2:39	123.5	4	495	290	" "							"	"
2:42	114	4	456	267	" "							"	"
			Same as above, with 12252 shell as control.										
2:49	108.5	4	434	254	flash-over							"	"
2:51	109	4	436	255	" "							"	"

TEST SHEET 10—(OHIO INSULATOR CO.)
OSCILLATOR TEST DATA

Date March 2, 1921

Time	Gen. volts	Gen. amps.	Primary turns number	Primary turns spacing	Primary capacity mfd.	No. of secondary turns	Sphere gap setting	Size of spheres	Kv.	Secondary current milliamp.	Wavemeter setting	Coil no.	Freq.	Water and lb. pressure	Remarks Photo No.	Time	Exp.
Test 2:50	No. 7 525	150	10	2¼"	0.3813	1620.0	20"	No arc		1.8				Dry	12	..	32
Test 3:05	No. 8 520	150	"	"	"	"	20"	No Arc		1.75				"	1	1 min.	32
Test 3:14	No. 9 525	150	10	"	"	"	20	No. Arc		1.8, 1.82					2	1 min. volta 2 min.	32
Test 4:18	No. 10 525	150	10	"	"	"	20	No. Arc		1.8					5	1¼ min. 2 min.	volt. 32
4:20	525	150	"	"	"	"	20	50 cm.	545	1.82					6	7 sec.	32
4:28	..	..	"	"	"	"	4½	"	211	0.6	No corona						
4:30	..	..	"	"	"	"	5½	"	250	0.95	No corona						
4:32	..	..	"	"	"	"	6½	"	282	1.1	corona showing						

Dimensions and Output

BY LAWRENCE E. WIDMARK
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The writer undertakes to demonstrate that the expression $D^2 L$ (D = Rotor diameter, L = Net iron length) as used in the electrical design does not meet modern requirements. He advocates the replacing of it by $D \times V$, where V stands for the volume of the rotor. The reasons and advantages of the new form are expounded and it is shown how a series of extremely useful relationships follow the new formula.

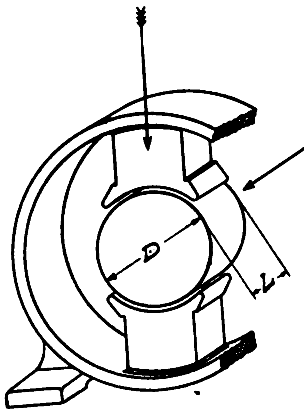
SINCE the time when the output of electrical machines was limited by the necessity of providing good heat radiating rotor surface and a low value of ampere-conductors per rotor periphery the custom has survived of calculating the electrical "capability" of a machine in reference to $D^2 L$. (D = Rotor diameter, L = Net iron length.)

Our modern way of making internally ventilated machines and the freedom with respect to ampere-conductors won by the interpoles really makes "$D^2 L$" an antiquated tool for the designer. The expression cannot be longer considered a suitable measure for the electrical sizing up of a machine.

As a matter of fact this expression takes care of three things, heat radiation, easy condition for commutation, and the magnetic flux. Only the last one is a fundamental and natural consideration. The other two vary from day to day in accordance with the prevailing trend of the current design.

Let us now try instead to find an expression that is confined to the two paramount considerations of electrical design, *viz*: the *electric flow* and the *magnetic flow*. After provision has been made in this respect it is up to us designers to arrange the dimensions so as to get the best results, but the foundation formula should be independent of our varying troubles.

The output of a machine is obviously the product of these two flows. Now what is the limiting dimension of the magnetic flux? The cylindrical area of the rotor or $\pi D L$. And what is the limiting dimension in regard to the total current volume? The armature



copper area, without doubt. This area must necessarily be limited by the total area of the slots that can be contained in the rotor disk. The conclusion is that finally the area of the rotor disk or $\frac{\pi D^2}{4}$ determines the electric flow.

In accordance with the above we shall get the expression for the possible output of the machine by multiplying the two limiting values $\pi D L$ and $\frac{\pi D^2}{4}$, and we have arrived at the solution:

That the possible output of an electrical machine should be considered as proportional to the *product of the rotor volume by the diameter thereof or* $V \times D$ and *not* proportional to $D^2 L$, or the rotor volume only.

For the practical application of this result we proceed as follows. Take the total electrical load of the rotor in watts and divide same with the rev. per min. The result we will call *watt-revolutions*. If we then have the rotor volume expressed in cubic inches we shall by dividing same by the watt-revolutions get *cubic inches per watt-revolution* which we denote by θ. Then $\theta \times D$ will turn out to be a considerably stable constant determined by three factors, *viz*:

1. The proportion of armature copper to the disk area.
2. The current density.
3. The magnetic density, total flux per square inch taken all over the rotor surface.

These three factors, of course, do not remain constant for all sizes of machines. Their general grouping, however, make the resulting constant comparatively stable. The current density is decreasing with larger machine units, while the proportion of copper section is affected in two opposing ways. When the machine size is increased the slot area compared with the disk area is likely to decrease but on account of less space required for insulation the copper per slot will increase. The variation in the magnetic condition will tend to offset the result created by the changes in the other two conditions.

The result is that the new expression gives an exceedingly good standard value for small and medium sized machines where on account of competition a standard is most necessary. For larger sized machines the constant is slowly increasing. As is well-known the old constant is no constant whatsoever for the lower end of the machine series. It is first stabilizing when it comes to larger machines.

Business consideration prevents me from discussing the numerical value of the constant, in accordance with the new expression.

A most interesting development of the expression is a study of how the different selections of the principal dimensions will affect the design of ordinary induction motors.

Starting from $V \times D = C$ or here given the form of $D^3 L = C$, we easily arrive at the following results when choosing different rotor diameters. As stator dimensions follow rotor diameter, both stator and rotor are included.

Iron length $= \frac{C}{D^3}$, inversely proportional to the cube of the diameter.

Rotor surface and total flux $= \frac{C}{D^2}$ inversely proportional to the square of the diameter.

Copper section $= C\,D^2$, proportional to the square of the diameter.

Copper volume of end connections $= C_1 D^3$, proprotional to the cube of the diameter.

Copper volume of iron length of copper $= \frac{C_2}{D}$ inversely proportional to the diameter.

Iron volume $= \frac{C_3}{D}$ inversely proportional to the diameter.

If we now try to find what selection of dimensions gives the most favorable machine we have

$$\underset{\text{(end connection copper)}}{C_1 D^3} + \underset{\text{(Copper in iron)}}{\frac{C_2}{D}} + \underset{\text{(Iron volume)}}{\frac{R\,C_3}{D}} = \text{Min.} \qquad (1)$$

C_1, C_2, and C_3 as per above, R reduces the iron volume to its copper value. For instance, copper being five times more expensive than the laminations, R equals 1/5.

Differentiating equation (1), we get

$$3\,C_1 D^2 - \frac{C_2 + R\,C_3}{D^2} = 0 \qquad (2)$$

or as we also could write it

$$C_1 D^3 = \frac{C_2 + R\,C_3}{3\,D} \qquad (3)$$

Comparing this result with equation (1) we now get the interesting fact that the cost of the active material of an induction motor reaches a minimum when *the value of the end connections equals one-third of the value of the iron and the copper embedded therein.*

Equation (3) also gives the most favorable value of the rotor diameter:

$$D = \sqrt[4]{\frac{C_2 + R\,C_3}{3\,C_1}} \qquad (4)$$

A preliminary design has for instance, given the following values:

Rotor diameter 9 in., iron length 6 3/4 in., total weight of copper 29 lb., (16 lb. for end connection and 13 lb. for copper embedded in iron). Weight of iron used for stator and rotor punchings 325 lb.

It is desired to check up the design for ratio of iron cost to copper cost of 1 to 5 and we proceed as follows:

$$C_1 D^3 = 16 \text{ lb. for } D = 9 \text{ in., } C_1 = \frac{16}{729}$$

$$\frac{C_2}{D} = 13 \text{ lb., for } D = 9 \text{ in., } C_2 = 117$$

$$\frac{C_3}{D} = 325 \text{ lb., reduced to copper } \frac{R\,C_3}{D}$$

$$= 65, \text{ for } D = 9 \text{ in., } R\,C_3 = 585$$

Using equation (4) we get $D = 10$ in.

Thus 10 in. is the proper dimension under the given cost proportion and not 9 in.

In this connection, also note that the numerical value of the diameter is very slow to change when the ratio between copper and iron cost is varied. This of course depends upon the bi-square root. Suppose for instance the ratio should be 25 per cent different. This will only affect the value of the diameter about 5 per cent.

It is also possible, however, to get a rational expression showing how the internal design of the machine affects the most favorable proportion of diameter to iron length.

Let the total copper section, (both for stator and rotor) be α per cent of the rotor disk. Let β be the proportion of the lengths of the end connections to the length of the diameter.

We will then have the following expression for the end connection copper:

$$\alpha \frac{\pi D^2}{4} \times \beta D$$

For the copper embedded in iron:

$$\alpha \frac{\pi D^2}{4} \times L$$

And for the copper value of the iron used for punching the disks:

$$R \times P^2 \times D^2 \times L$$

P stands for the proportion of stator diameter to rotor diameter and the disks are punched out of material in squares with sides equal to $P\,D$.

Using the relation for minimum cost set forth in equation (2), we get:

$$\alpha \frac{\pi D^2}{4} \beta D = \frac{1}{3} \left(\alpha \frac{\pi D^2}{4} L + R\,P^2 D^2 L \right)$$

or

$$\frac{D}{L} = \frac{\alpha + \frac{4}{\pi} R\,P^2}{3\,\alpha\,\beta}$$

As an example, we have for a certain size of machine the following values:

α = 17 per cent
β = 1 (four-pole machine)
P = 1 1/2
R = 1/5.

We then obtain for $\frac{D}{L} = 1.45$

A more or less unexpected result of above formulas is that even for four and six-pole machines, the comparatively long type seems to be by far the most favorable design and that the increase in weight of the end connections with the cube of the diameter proves to be a terrible handicap for the short, large-diameter machine.

The advantages of the suggested expression *versus* the old one may be summed up as follows:

The numerical value of the new expression starts with a final value; it is practically a "constant constant" for the commercially most important lower end of the machine series and begins to vary first with larger machines. The numerical value of the old expression starts with infinity, and is practically valueless as a guide for smaller and medium-size machines on account of its variable value

The new expression leads to a very interesting study of the most favorable design of a machine as regards cost and how the design is affected by different conditions. If the old expression is used in a similar way it will be found that the iron volume being a constant, disappears after differentiation and that therefore the cost of the iron will not be taken into consideration at all.

The new expression is easily calculated from magnetic and electric densities referring to strictly determinable surfaces of the machine, *viz.*, the rotor cylindrical surface for the flux and the disk area for the electric load; instead of referring to the comparatively indefinite induction of the air gap and the artificial and unnatural conception of current volume per rotor periphery,—or amperes per inch.

The new expression is clothed in a practical concrete and tangible form, *viz.*, cubic inch rotor volume per watt-revolution, which, multiplied by the diameter, gives a three figure numerical value, which of course is much preferable to the practical man than the form of the old expression:

$$\frac{D^2 L \times \text{rev. per min.}}{\text{Kw.}} = C\,10^5.$$

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Advances in the Art of Waterwheel Designs and Settings

By W. M. WHITE

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THE UTILIZATION of our natural resources for the development of power, its transmission and the employment of that power to relieve man of burdensome toil, has been an outstanding feature in the progress of Western civilization during the past half century.

The advance of communities, states and nations may be read in the record of the percentage of mechanical power utilized per man. An English statesman recently said in open Parliament meeting that the reason why American manufacturers can pay twice the wage paid the English workman and yet compete in the markets of the world, is because each American workman has behind him twice the developed horse power per man that the English workman has behind him.

Of the total power developed in the United States, that furnished by water power forms no inconsiderable part. The amount of power now developed from water is approximately nine million horse power. It has been estimated that fifty million horse power can be developed from the rivers within the borders of the United States. Of the nine million horse power, by far the major portion has been developed in the last thirty years and a curve expressing relation of time and power developed would be parabolic in form with an upward trend.

Power was first developed from water by the Chinese about two thousand years before the birth of Christ. They used paddle wheels and buckets attached to the rim of a large wheel placed in the rapidly flowing stream for the purpose of raising water for irrigation.

The early American types of waterwheels were peculiarly adapted to the locality in which they were made. From the New England States with their meandering streams and low falls came the inward flow, reaction turbine wheels, and out of the mountainous West with its precipitous streams and great falls, came the Pelton or impulse wheel.

The work of J. B. Francis of Lowell, Mass., was a notable contribution to the art, resulting in the development of the inward flow, axial discharge wheel which is essentially the present waterwheel runner of the reaction type. Splendid results were obtained by the early designers by the cut and try method. The determination of the flow of water under given conditions is difficult and is usually computed from empirical formulas founded on experimental data. The problems involved do not lend themselves to easy mathematical treatment. For example, the regulation of a hydroelectric unit with pipe lines involves the varying pressures at the wheel caused by the inertia of the water in the pipe line caused by the varying of the velocities of the water in the pipe line.

Some splendid approximate, mathematical formulas have been developed recently for determining these pressures with given pipe line conditions, but these formulas do not give exact or correct values for all conditions.

It is not difficult to set up differential equations which give proper relative values to the variables involved, but some of these equations are not soluble by the present methods available for simplifying equations.

The electrical quantities involved in the design of electrical apparatus are more readily determined than those quantities entering into hydraulic problems. The loss (friction) in an electric conductor varies directly as the current (velocity). The loss of head or friction in a pipe varies as the nth power of the velocity. The former involves equations of the first degree; the latter, equations of the second degree. The value of n is 2 for the starting of water in motion and the stopping of it; that is, v equals $\sqrt{2\,g\,h}$, and the value of n is approximately 1.85 for computing the loss by friction in pipes. $H = K\,V^{1.85}$

It is encouraging to the hydraulic engineer to know, as the writer has recently been assured, that a Professor in one of the Western colleges is now working on a table of functions somewhat similar to the logarithmic functions which will probably enable reductions of certain, now insoluble, differential equations to be made and thus enable us to make use of an exact formula in solving the problems involved in this line of work.

The energy for the production of power from water is the product of the weight of the water and the head or fall utilized. Broadly speaking, the natural configuration of the locality of the power developed, determines the head or fall available, and the drainage area and climatic conditions contributory to that locality are the principal factors in determining the quantity of water. As it seldom occurs that the configuration of the locality and the drainage area and climatic conditions are the same, so it seldom results that one hydraulic power development is an exact duplicate of the other. The hydraulic engineer, therefore, has no one fixed condition to begin with.

From the above it results that each power development requires special study to select that method and type of development suited for the particular location. The problem of finding the proper power house and dam location in the maze of contour lines calls for minute investigations and studies. It requires a great deal of time and the working out of the costs of many

Presented at the Annual and Pacific Coast Convention of the A. I. E. E., Salt Lake City, June 21-24, 1921.

preliminary studies of power house design of that particular site in order to find the proper relation of dam, pipe line, power house, tailraces, transmission lines, hydroelectric machinery, and living conditions which will result in the most economical and satisfactory development. The advance of the art must be taken into consideration because what treatment was satisfactory for a given development even five years ago can now be improved by making use of recent advances in the art of waterwheel design and settings.

The modern trend is to develop completely any given power site. The number of units in the given plant is dependent upon the service to be rendered by the given plant. The network of transmission lines is now becoming so extensive that isolated power plants are the exception rather than the rule, as formerly. In an isolated power plant it was necessary to divide the development into several units, usually at least four, so that continuity of service could be maintained by allowance for repairs and renewals. Most of the isolated early developments have now grown to huge dimensions having many plants interconnected with themselves and, in many cases, interconnected with adjacent companies, and now many companies have lines of interconnection reaching into several states. The hydroelectric station in the large systems today is the unit just as the individual waterwheel and generator were the individual unit years ago. The engineer is at liberty, therefore, to handle this unit in any manner which will make for economy in construction, efficiency in operation, and reliability of service. All three of these considerations really demand the same thing—the largest single unit which can be installed in the particular development under consideration, thus doing away with several small units with an additional spare unit.

Speed

Having determined upon the size of unit for a particular setting, the speed of the unit is practically fixed for that head. A formula which has been used for sometime as fixing the upper limits of speed is as follows:

$$\text{rev. per min.} = \frac{\left(\dfrac{5050}{H+32} + 19\right) H^{5/4}}{\sqrt{\text{h. p.}}} \qquad (1)$$

Where

H equals head acting on the turbine

h. p. equals the maximum horse power of the turbine.

The formula (1) applies to a single runner and, in the case of multirunner units, the maximum horse power of the unit is to be divided by the number of runners and the horse power per runner substituted in the formula (1).

The maximum horse power of the turbine is usually from 15 to 25 per cent more than the actual power required to drive the combined unit at its best efficiency. This relation results from the fact that the maximum efficiency of a waterwheel occurs at from 0.8 to 0.9 load, depending upon the type of runner used and the desire to have overload capacity on the turbine. The rev. per min. given by the formula (1) is altered to conform to synchronous speed. The above formula is not rigidly adhered to, although it has been arrived at by incorporating in its factors the experience of all of the waterwheel builders for many years past. Each manufacturer has a line of developed waterwheel runners and is frequently in position to make a selection of speed which will result in considerably lower cost to the customer because of developed apparatus, and in all cases a reliable waterwheel builder should be consulted as to speed. The matter of the selection of speed will be again referred to under the subject of "Specific Speed."

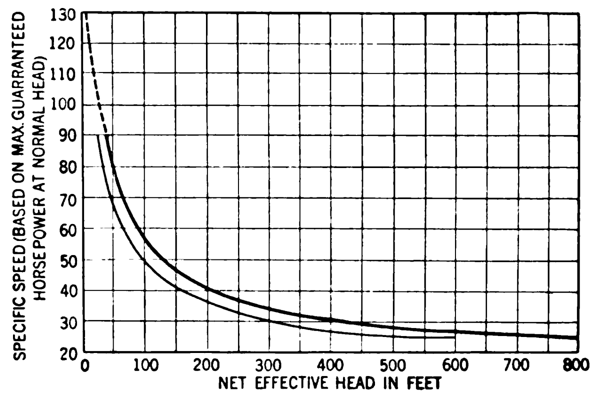

FIG. 1—SPECIFIC SPEED LIMIT CHART

FORMULA

$$N_s = \frac{5050}{H+32} + 19 \text{ in ft.} = \text{ft-lb. lb. units}$$

$$N_{s_m} = \frac{22{,}500}{H+32} + 84 \text{ in metric units} = 4.45\, N_s$$

Insert H in feet in both formulas.

Specific Speed

Specific speed is the speed at best efficiency which a given runner will make when reduced homologously to such size that it will produce one horse power under one foot head. The value of the specific speed of a given runner fixes definitely that runner as a type with relation to all other runners. The formula for specific speed is as follows:

$$N_s = \text{rev. per min.} \frac{\sqrt{\text{h.p.}}}{H^{5/4}} \qquad (2)$$

For simplicity of computation in common practise, the horse power of the turbine is reduced to h. p_1. That is, the horse power which that particular unit would give under one foot head. This is obtained by dividing the horse power by the three halves power of the head.

The rev. per min. is reduced to the number of revolutions that particular turbine would give under one foot head, or, namely, rev. per min_1. This is obtained by dividing the rev. per min. of the given

turbine by the square root of the head; therefore, formula (2) becomes:

$$N_s = \text{rev. per min.} \sqrt{\text{h. p.}} \qquad (3)$$

The curve shown in Fig. 1 expressing relation of specific speed and head was determined by plotting the specific speeds of practically all of the noted plants in the United States and some abroad with relation to the head under which they were operating, noting on the point so plotted those plants on which no pitting occurred and those on which pitting of the runner did occur, or noting any other unstable or unsatisfactory performances of plants in operation. A curve was then drawn below the points representing plants on which pitting occurred or which were unsatisfactory on an average, and above the points representing all of the plants on which pitting did not occur and which were satisfactory and efficient in operation. A curve

$$Y = \frac{5050}{H + 32} + 19 \qquad (4)$$

plotted with vertical ordinate as specific speed and horizontal ordinate as head gives the specific speed curve referred to above and is the factor used in the derivation in the original equation (1). Steady advances are being made and no doubt speeds higher than those indicated in formula (1) will ultimately be adopted. There is probably no other thing in the design of a hydroelectric plant that received more discussion than the question of the speed of the units. There are several contending forces: The electrical engineer desires usually the higher speeds in order to cheapen the cost and frequently increase the efficiency of the generator. On the other hand, the waterwheel designer prefers his lower speed usually for better efficiency throughout and, certainly, for higher efficiency at lower or part gate loads, and for freedom from troubles in the field such as pitting, erosion and vibration.

It does not always follow that the speed as given by formula (1) does result in a satisfactory waterwheel unit, but the most skilled designers are now enabled to produce those speeds and sometimes higher without dangerous pitting or cutting.

The size of waterwheel units has steadily increased to such a point that now the cost of the generators does not vary as widely with the change in speed, so that it may result that, in the design of larger units now in general contemplation, this troublesome case may settle itself.

Speed Regulation

The great inertia of the moving mass of water to and from the waterwheel produces difficulties in the regulation of the speed of the waterwheel unit which can best be controlled by making use of the inertia of the revolving parts of the waterwheel and generator. The greater the inertia of the enclosed supply water, the greater the $W R^2$ necessary to give good regulation. The factors entering into the control of the speed are:

(a) the time (t) in which the water is shut off from or turned on the unit.

(b) the increase or decrease of the effective head on the turbine occasioned by such change.

(c) the inertia of the revolving mass which resists change of speed by acting as a reservoir for the energy unabsorbed otherwise.

The governing apparatus is frequently unfairly charged with poor regulation, when all that apparatus can do is to open or close the turbine gates within a predetermined time (t) when actuated by a change in speed. The formula most commonly used for quick computation of speed change, although not exactly correct, gives results well within the limits required.

$$\Delta = \frac{800{,}000 \times \text{h. p.} \times t}{\text{rev. per min.}^2 \times W R^2} \qquad (5)$$

Where

Δ is the ratio of increase or decrease in speed

h. p. is the horse power suddenly thrown on or off

t is the time for the movement of the gates of the turbine

$W R$ equals the inertia of the rotating parts of the waterwheel and generator.

Formula (5) is used only for open flume turbines or where the change in pressure or head resulting from the change in flow, is too small to be considered. For cases where load off results in an increase of head at the turbine inlet, the following formula may be used with good results:

$$\Delta = \frac{800{,}000 \times \text{h. p.} \times t}{\text{rev. per min.}^2 + W R^2} \left(1 + \frac{\Delta H}{H}\right)^{3/2} \qquad (6)$$

In case of load suddenly thrown on, the formula becomes:

$$\Delta = \frac{800{,}000 \times \text{h. p.} \times t}{\text{rev. per min.}^2 \times W R^2 \left(1 - \frac{\Delta H}{H}\right)^{3/2}} \qquad (7)$$

Where

H equals effective head, feet

ΔH equals change in head, feet

For a more thorough discussion of speed regulation the reader is referred to Mr. Arnold Pfau's paper, "The Speed and Pressure Regulation of Hydraulic Turbines," copies of which the author will be pleased to furnish.

The resulting change of effective head operating on the turbine caused by the movement of the gates within the time (t) is dependent upon the velocity and length of the column of water. Manifestly open flume turbines are easiest of all to regulate. Turbines having long pipe lines with high velocities cause greatest difficulties in regulation. Modern governors are equipped so that they may be readily adjusted for moving the gates open or closed in a predetermined time, usually a different time for closing and opening

the gates in order to avoid synchronous waves in the pipe line. An important factor to be taken into consideration is the fact that the horse power to be inserted in formula (5) is the change in horse power which is developed under the changed effective head acting on the turbine, due to the change in pressure occasioned by the quick movement of the gates. Reference was made at the beginning of the paper to the complicated mathematical solution of the problem of regulation, but a fair understanding of pressure changes at the turbines may be had from the following formula.

$$H = \frac{L\,V}{G\,t} \tag{8}$$

H equals the increase or decrease in head
L equals the length of the water column in feet including draft tube
V equals the change in the average velocity of the water in feet per second within the time (t)
G equals the value of force of acceleration of gravity equals 32.2 ft. per sec. per sec.
t equals the time in seconds in which the change in velocity is made.

There are many factors which enter into the exact mathematical solution such as the elasticity of the pipe line, the ratio of change in velocity for any small increment of time during the time (t) and the ratio of the increase or decrease of the pressure for any small increment of time during the time (t). There are certain peculiar conditions for length of pipe line, velocity in the pipeline and time of movement of the turbine gates which will result in an actual increase of power on the turbine as the gates are closed. In other words, the increment of increase of head is greater than the decrement of the decrease in quantity. The length of the pipe line is fixed by the natural conditions surrounding the development, but the velocities within the pipe line can be controlled and predetermined by the selection of the proper size of pipe line. The cost of the increase in the diameter of the pipe line may be excessive and it frequently results that $W R^2$ may be secured in the generator or in a flywheel at much less cost. If the pipe line conditions are rather rigid and fixed, it becomes necessary to provide proper $W R^2$ to secure the desired regulation as may be computed from formulas (6) and (7). The regulation constant has been determined by observing in power plant operation the $W R^2$ and other conditions necessary for reasonable regulation. The constant is set up by the following equation:

$$K = \frac{(\text{rev. per min.})^2 \times W R^2}{\text{h. p.}} \tag{9}$$

It will be noted that the constant K includes three of the principal factors of equations (5) (6) and (7).

The value of K should not be less than four million for open flume construction and runs as high as fifteen million on some of the successfully regulated plants having long penstocks with reasonably high velocity.

As waterwheel runners have a very small $W R^2$ compared with that of the generators which they drive, the generator should have a constant for regulation of not less than four million as stated above.

Pressure regulators are used in connection with the governors to reduce the rise of pressure on closing of the gates. They are expensive, however, and where it is possible to obtain substantially equal regulation by increasing the $W R^2$ and omitting the pressure regulators, with consequently slower governor operating time at anything like the same cost, it is preferable.

Runner

The most important single piece in the make-up of the water wheel is certainly the runner. The function of all the headworks, supply lines, casings, speed rings, and guide vanes, is to deliver to the runner the maximum amount of energy with proper relation of velocities and pressure, and the function of the proper draft tube or regaining devices beyond the wheel is to return to the runner in the form of added head, as hereafter explained, the maximum amount of energy. The function of the runner, therefore, is to transform the maximum amount of energy delivered to it into mechanical power on the waterwheel shaft.

The diameter of the runner is fixed by the relation

$$\pi D N = \phi \sqrt{2 g H}$$

Where
D = diameter of runner in feet.
N = rev. per min. ÷ 60.
ϕ = coefficient.
H ÷ the effective head on the turbine as measured from the equivalent pressure head at the entrance to the casing plus the distance from the point of measurement to the level of the tailwater in the tailrace.

The value of ϕ varies from, say, 0.6 for very high-head wheels to, say, 0.8 for low-head wheels. The diameter (D) is the diameter of the circle touching the intake edges of the runner vanes along the center plane of the guide casing.

For purpose of explanation let us consider a runner of normal specific speed, say 35, (shown in Fig. 3) where ϕ would equal 0.72, and where the water delivered from the guide vanes to the runner would have its energy about equally divided into velocity and pressure. The runner, therefore, receives the water in a whirling vortex, yet under a pressure of about one-half of the head, and the shapes of the runner vanes are formed so that the water in passing through the runner is directed backward to the rotation of the runner and is discharged from between the runner vanes at a velocity substantially equal to the forward velocity of the runner, so that theoretically and ideally the water should flow parallel to the shaft into the draft tube with a minimum loss, considering the di-

ameter of the discharge of the runner band and the necessary velocity at that point to pass the quantity of water required. This condition of axial discharge is not attained and as a matter of fact is not desired for maximum efficiency. Pitot tube traverses made across the draft tube near the runner band show that usually the water at best efficiency whirls with the runner near the outer band and against the rotation of the runner near the inner band. The amount of energy discharged from the runner, therefore, is greater than that given by

$$\frac{V^2}{2G}$$

where V is the average velocity of the water flowing axially through the upper end of the draft tube where it joins the runner.

The number of vanes or buckets in the runner varies from thirteen to twenty-four depending upon the specific speed of the runner and the head under which it operates. The condition to be satisfied in the selection of the number of vanes is that number which will form passages through the runner sufficiently smooth in shape to avoid eddies and cross currents, and yet not too many vanes as contrasted to the friction which is introduced by the accumulated surface of too many vanes. The diameter of the runner at discharge is contracted until a balance is arrived at between the loss due to the velocity discharged from the runner and the friction loss saved by reduction of vane surface.

Another factor entering into the number of vanes is the question of pitting or erosion. Too few vanes will not give a proper channel between the vanes which results in the water leaving the back side of the vanes near the outer band creating a vacuum and slapping, action causing mechanical erosion, or creating a vacuum in which collects nascent oxygen which eats away the vanes, or a sudden release of air from the water setting up currents causing electrolysis. All or any of the above reasons may be the real one; you may take your choice. The higher the specific speed the greater the ratio of the diameter of discharge of the runner to the nominal diameter D of the runner. If the specific speed is increased the discharge band of the runner is gradually enlarged with respect to the nominal diameter and runners of 100 specific speed have a diameter of the discharge of the runner of 1.3 times the nominal diameter.

As the specific speed is increased the question of friction becomes the controlling element, consequently, this results in a reduction of the number of vanes, and a reduction of the size of the outer band which at maximum specific speed leads to the Nagler runner wherein the outer band is eliminated and the number of vanes reduced to a minimum. Three vanes in this type of runner have been found to give good results.

The problem of determining mathematically the results of flow in a straight pipe are so difficult, as set forth at the beginning of the paper, that it is apparent that any mathematical formula attempting to predict the results of a given runner under a given condition involving as it does not only friction losses to the 1.85 power but also centrifugal force, shock losses, disk friction losses and reaction losses, certainly has no place in this paper. The reader will be interested, we hope, in a statement of the various types of runners. Probably no single part of any apparatus has been fixed more by cut and try, and experimental methods than the runner of a waterwheel.

Fig. 2 is a runner having a specific speed of 21.5 designed to operate under a head of 415 ft. Fig. 3 is a runner of 34 specific speed designed to operate under a head of 215 ft. Fig. 4 is a runner of 67.7

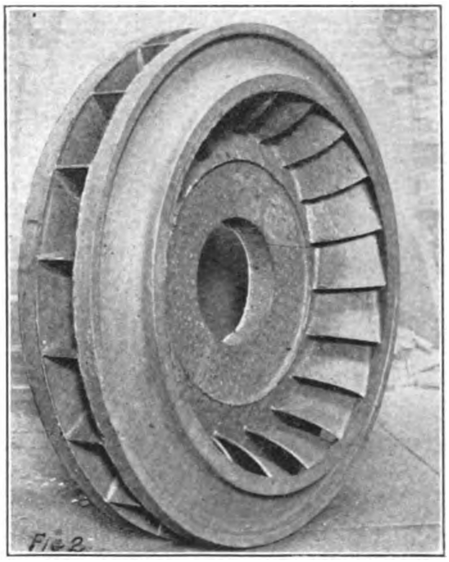

Fig. 2—55-in. Runner
8000-h. p., 550-ft. head, 720-rev. per min.

specific speed designed to operate under a head of 68 ft. Fig. 5 is type No. 13 with a specific speed of 94 designed to operate under heads below 30 ft. Fig. 6 shows a four-bladed Nagler wheel having a specific speed of 137.

Runner Material

The runner being subject to greater stresses and greater wear, due to high velocities, than any other part of the waterwheel should have wearing rings and wearing surfaces wherever possible to facilitate ease of repair.

The ideal runner material is bronze and preferably without any zinc. A composition which has been found eminently satisfactory for this purpose is composed of 90 parts copper, 10 parts tin with a trace of phosphorous. It is economical to use bronze runners on high-head units providing the bronze runner is not too heavy in weight resulting in an excessively expensive runner. Cast steel runners have been used with ex-

cellent results on high-head and intermediate-head units. Cast steel is desirable on high-head large runners where the weight of the runner is heavy. Cast iron runners have been used with success on the highest

FIG. 3—SHOP VIEW OF 125-IN. CAST IRON RUNNER FOR THE LARGEST COMBINED HYDROELECTRIC UNIT IN THE WORLD

32,500-kv-a., 12,000-volt, 37,500-h. p., 215-ft. head, 150-rev. per min. For Niagara Falls Power Co., Niagara Falls, N. Y.

head turbines although they are not as satisfactory as the steel, because at these high heads the velocity of any foreign material flowing through the guide vanes

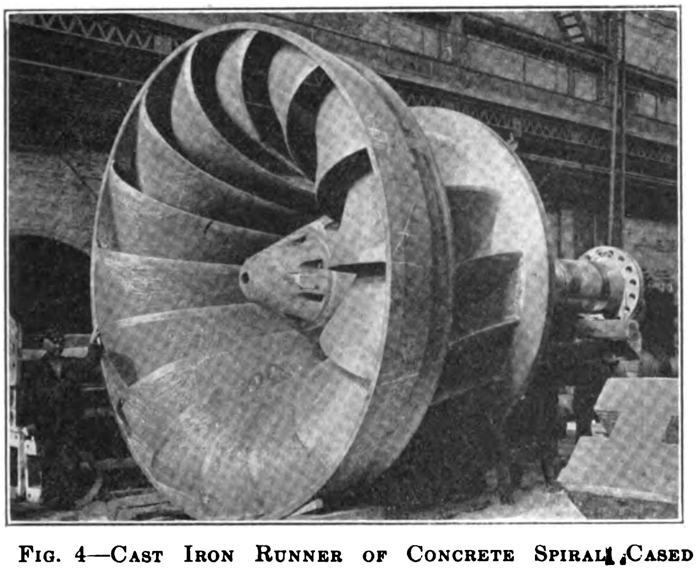

FIG. 4—CAST IRON RUNNER OF CONCRETE SPIRAL CASED TURBINES

35-ft. head, 90-rev. per min.

is so great as to break out portions of the cast iron. Cast iron runners are entirely satisfactory for all heads, say from 200 ft. downward.

A type of runner which has been used with considerable success for intermediate and low heads, is one in which the vanes are made of plate steel pressed from forms and then cast integral with cast iron crowns and cast iron outer bands. These runners have the advantage of having very smooth surfaces resulting in

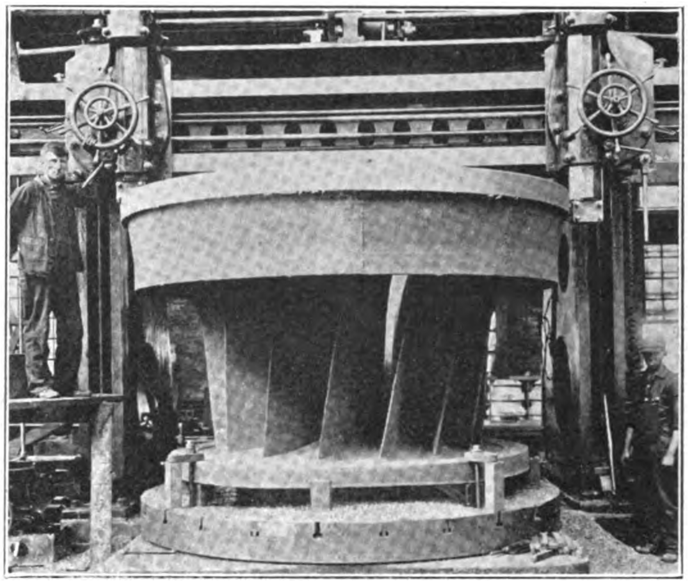

FIG. 5—80-IN. TYPE NO. 13 HYDRAULIC TURBINE RUNNER

With steel plate vanes being machined for single vertical open-flume hydraulic turbine. Three units each 600-h. p., 9-ft. head, 60-rev. per min.

less skin friction, and also have the added advantage that the runner vanes may be bent back into position after having once been broken by foreign material entering the runner, which does happen from time to time. Fig. 7 shows a good example of this type of

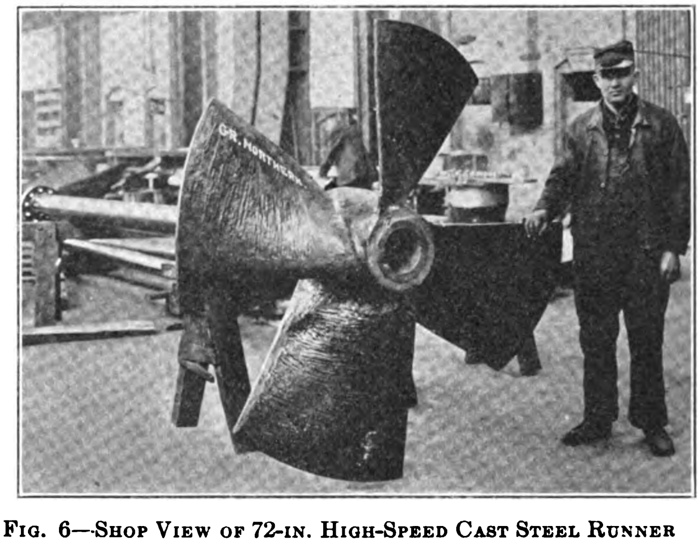

FIG. 6—SHOP VIEW OF 72-IN. HIGH-SPEED CAST STEEL RUNNER

Assembled on shaft and showing initial stages of assembling for balancing before finally grinding to a surface.

Designed for 600-h. p., 200-rev. per min., 17½-ft. head.

runner in which the vanes are made of plate steel ⅝ in. thick. Their specific speed is 102.5. These turbines are operating under 18.5 ft. head at 136.6 rev. per min., developing over 825 horse power.

The propeller type of wheel as described in Mr. Nagler's paper, Vol. 41, No. 12, A. S. M. E. *Journal*, entitled, "A New Type of Hydraulic Turbine Runner," has been in use with cast steel vanes cast solid with the hub. Another type in use is cast iron. Another interesting type is that in which the vanes are formed of plate steel and are cast integral with the hub.

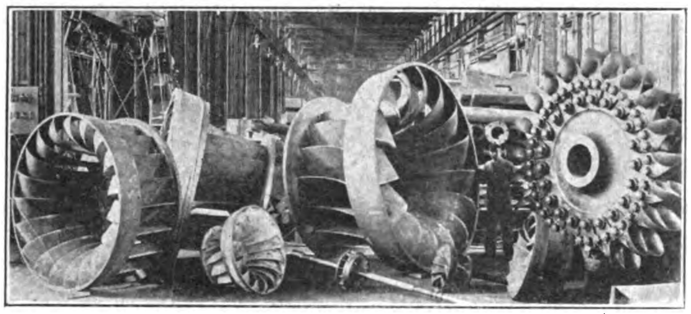

Fig. 7—Various Sizes and Types of Allis-Chalmers Waterwheels

For heads varying from 8 ft. to 2000 ft.
The two large runners in the center have plate steel vanes, as well as the small one just below the impulse wheel.

Draft Tubes

The twofold function of the draft tube is not usually understood. Its function is, first—to enclose and seal a passageway from the runner to a point below the surface of the tailwater so as to produce a suction action at the discharge from the runner, at least equivalent to the difference of elevation between the runner

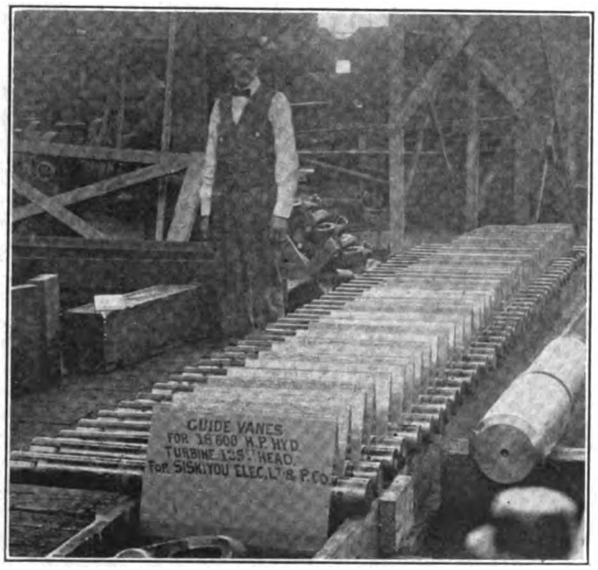

Fig. 8—Guide Vanes for Twin Horizontal Cylinder Steel Plate Casing Hydraulic Turbine

Two units, 125-ft. head, 18,600-h. p., 200-rev. per min.

and the level of the surface of the tailwater. Second—to transform the energy in the form of velocity head discharged from the runner into energy in the form of pressure head. This action may be a little more clearly understood by imagining a horizontal flow in which the flow at a given point is at a velocity equal to that being discharged from the runner, and further down stream where the cross-section is increased and the velocity slowed down, the elevation of the water will be found to be higher than at the upper point. The

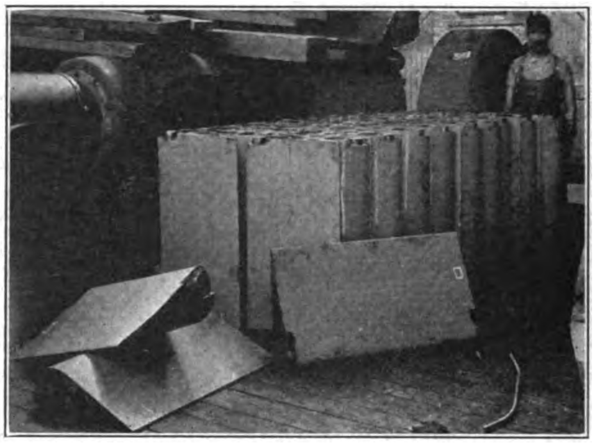

Fig. 9—Guide Vanes for Twin Vertical Open-Flume Hydraulic Turbine

Four units each 4,675-h. p., 30-ft. head, 100-rev. per min.

amount of this height is dependent upon the efficiency with which the conversion of velocity into pressure takes place. Therefore, the second function of the

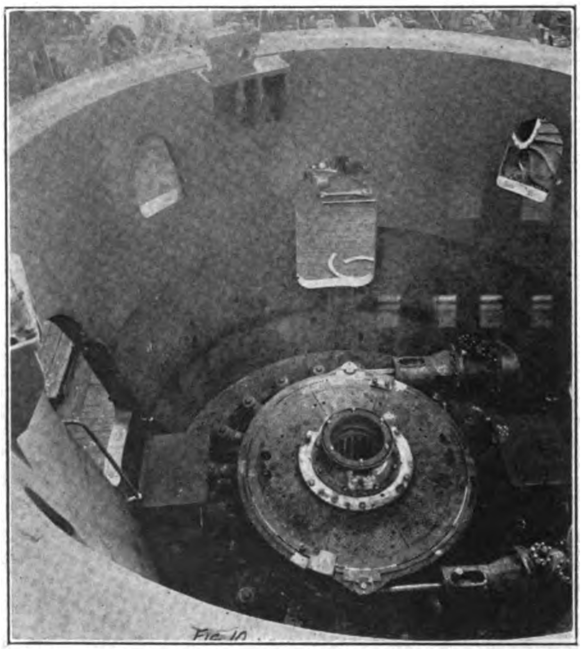

Fig. 10—Inside View of Single Vertical Turbine with Steel Plate Spiral Casing and Cast Iron Supporting Barrel for Generator

8,500-h. p., 53-ft. head, 100-rev. per min.

draft tube is to transform that velocity head into pressure head, thus creating an added suction at the discharge of the runner equal in amount to the velocity head times the efficiency of conversion. This amount added to the difference of elevation between the bottom

of the runner and the level of the tailwater gives the total added suction at the runner. By this conversion of velocity back into pressure and by this greater suction action being maintained at the discharge of the runner, the effective head on the waterwheel and runner up to the point of the discharge from the runner is greater than the head as measured from the equivalent level back of the waterwheel to the elevation of the

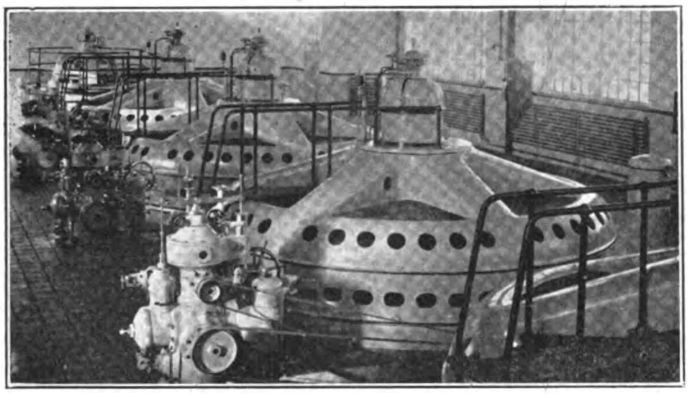

Fig. 11—Five Vertical A-C. Generators—Thrust Bearings Carried on Upper Housings

Direct-connected to 560-h. p., open-flume turbines with self-contained governors.

tailwater. Therefore, by the conversion of the velocity head into pressure head by means of some proper form of regainer and maintaining a greater suction at the runner by means of this discharged energy, the discharged energy is thus used by the waterwheel runner for the production of effective power.

A complete vacuum will cause the water to rise within it to about 34 ft. above the level of the outside water depending upon the air pressure at that particular locality and time. The height, therefore, to which a runner may be located above tailwater level is limited. We turn again to past experience for the factor fixing that height. It has been found that a runner of moderate specific speed may be placed so that the maximum suction at the base of the runner does not exceed 27 ft. theoretically. In determining the theoretical suction there is added to the elevation of the runner above tailwater the total velocity head in the water discharged from the runner, that is, to say, the efficiency of conversion is assumed to be 100 per cent. This is the limit of good practise, and where possible, other things being equal, this should be kept lower. As pointed out previously there is a limit to which the topmost point of the runner at its discharge can be placed. When large runners are placed with shafts in horizontal position the center line of the shaft is necessarily kept low with relation to the tailwater elevation in order to keep the top of the runner at discharge within the limits as set forth. This elevation of the shaft frequently depresses the generator into the foundations below the level of high tailwater and sometimes of even normal or low tailwater. This is a good reason for the adoption of the vertical shaft. An interesting setting is that of the Kerckhoff Station of the San Joaquin Light & Power Corporation where the turbine pit is excavated from granite and draft tubes driven from the bottom of the excavation out to the river channel as illustrated in Fig. 21. This design enabled the avoidance of cofferdams which would have been very expensive at this location.

The regain of energy from the velocity discharged from the runner may be accomplished more or less effectively by—

(a) straight conical tubes.
(b) curved draft tubes.
(c) hydraucone regainers.

Straight conical tubes will regain the energy with high efficiency provided the space available within the power house foundations is sufficiently ample to permit the installation of a long conical tube having a length of preferably more than four times the diameter of the draft tube where it joins the runner. Most of the curved draft tubes are a delusion and a snare. Recent investigations along these lines have shown that curved tubes now in use are so poor in regaining efficiency as to seriously detract from the power plant efficiency.

The Hydraucone Regainer is a new device for regaining pressure from velocity within the limited space available within the power house foundations. It contemplates spreading out the flow of the water on some

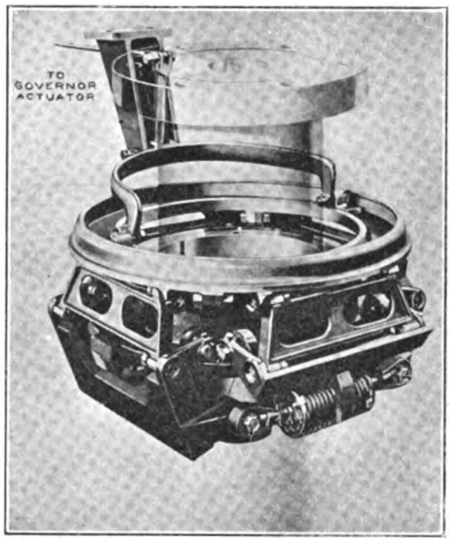

Fig. 12—Direct-Connected Flyball Governor

For mounting on the main shaft.

form of either flat or conical plate and then placing around the surface of the stream an envelope of gradually increasing greater capacity over that required to just enclose the free shape. In the case of the proper conical center a gradually enlarging capacity may be obtained wherein the pressure from velocity is regained. The conical center is not essential as tests have proved that substantially the same results have been secured

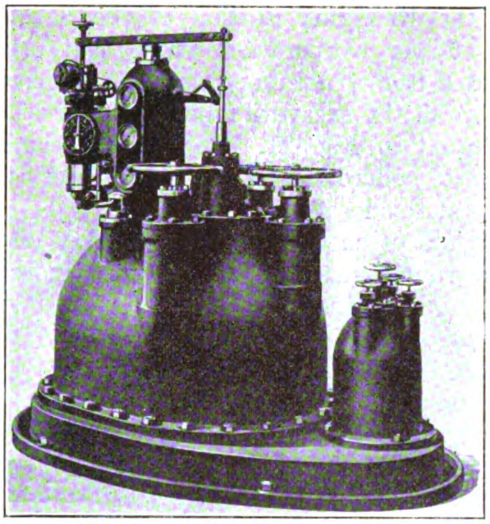

FIG. 13—SPECIAL CENTRIFUGAL CONTROL STAND FOR TYPE NO. 4 ALLIS-CHALMERS HYDRAULIC TURBINE OIL PRESSURE GOVERNOR USED IN CONNECTION WITH FLYBALLS MOUNTED ON THE TURBINE MAIN SHAFT BELOW THE GENERATOR

Used for Hydraulic Power Co., Niagara Falls.
Vertical unit 37,500-h. p., 214-ft. head, 150-rev. per min.

by the omission of the conical center even in regainers having the upper walls especially designed with reference to the cone center. This result, however, may be accomplished only when a conoidal chamber does not vary too widely from the hydraucone which would be formed upon the particular base used. The outwardly extending passages in this form of regainer increase the efficiency of the waterwheel at full and particularly at part loads, since the centrifugal force of the whirling water may be effectively utilized in these outwardly extending passages.

A summary of the experiments conducted in perfecting the Hydraucone may be found in the paper, "The Hydraucone Regainer, its Development and Application in Hydroelectric Plants," which was read by the writer before the Spring 1921 Meeting of the American Society of Mechanical Engineers.

The curved draft tube is illustrated in Fig. 17. The Hydraucone Regainer is illustrated in Fig. 14. The Hydraucone Regainer has an efficiency of conversion of between 70 per cent and 80 per cent depending upon the available width between the walls of the power house foundations.

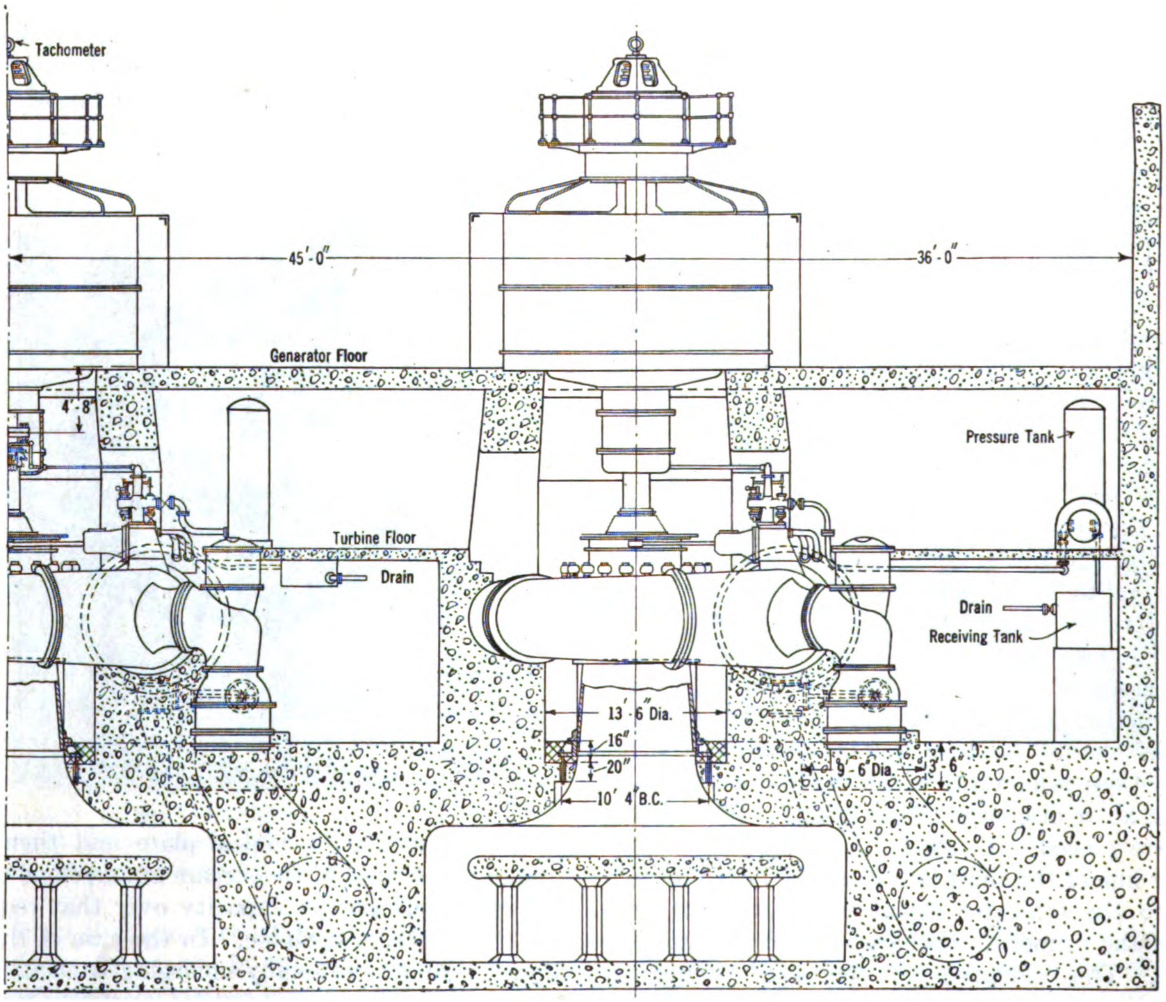

FIG. 14—VIEW OF 40,000-H. P. 421.5-FT. HEAD, 257-REV. PER MIN. TURBINES
With integral governor and direct-connected flyballs and hydraucone regainer.

Shaft and Bearings

The main shaft is usually tapered and fitted into the hub of the runner. The shaft is sometimes made with a forged sleeve at the runner end to which the runner is secured by means of bolts. The former is

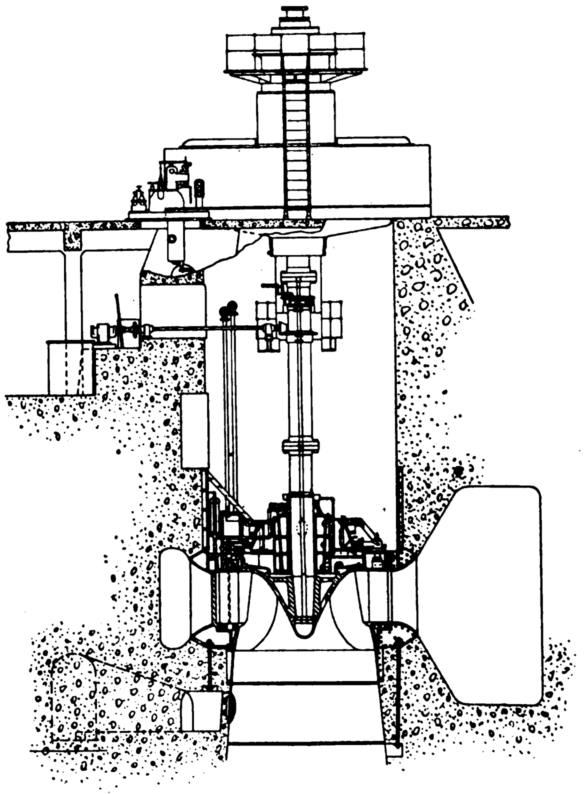

Fig. 15—Showing Oil Pump Gear-Driven from Main Turbine Shaft

Lignum-vitae bearing.
120-in. diameter cast iron runner.
17,500-h. p.—68-ft. head—100 rev. per min.
Wateree Power Co.

the preferred method of fastening the runner when lignum vitae bearings are used on the waterwheel, because by its use a renewable sleeve may be most cheaply and effectively applied to the shaft on which the bearing surfaces are caused to bear. It was formerly the practise to make these renewable sleeves on the shaft of bronze, but later tests have shown that rings forged from alloy steel provide surfaces of greater hardness and longer wear at no greater expense. It may be argued that the steel will rust, but the modern hydroelectric units are so well and strongly designed that they are seldom out of use, therefore, the question of rusting of the shaft is not a factor in arriving at the proper decision. Lignum vitae bearings have been used as illustrated in Fig. 18 for many years with good success. Where the speed is not too high and the generator is located immediately above the waterwheel, the lower generator bearings may be omitted and the one waterwheel bearing may serve as the lower guide bearing of the generator as well as the guide bearing of the waterwheel. An interesting installation embodying this feature of design is that of the Cheoah Plant of the Aluminum Company of America, equipped with Allis-Chalmers generators and Allis-Chalmers waterwheels, and lignum vitae lower bearing. This plant contains three 27,000-h. p. waterwheels operating under a head of 180 ft. Another interesting plant is that of the Tallassee Power Company at Badin, N. C., where an oil bearing is substituted for the waterwheel guide bearing and this oil bearing serves for the lower generator bearing as well as the waterwheel guide bearing. Wherever it is at all possible the waterwheel and generator shaft should be reamed together in the shops of the makers of one of the shafts, the bolts fitted to the shaft and the whole shaft turned in a lathe to be sure that the shaft turns true, before shipment. Open-hearth steel forgings of the simplest composition make the best waterwheel shafts because the problem involved is of stiffness rather than strength. It is most interesting to note

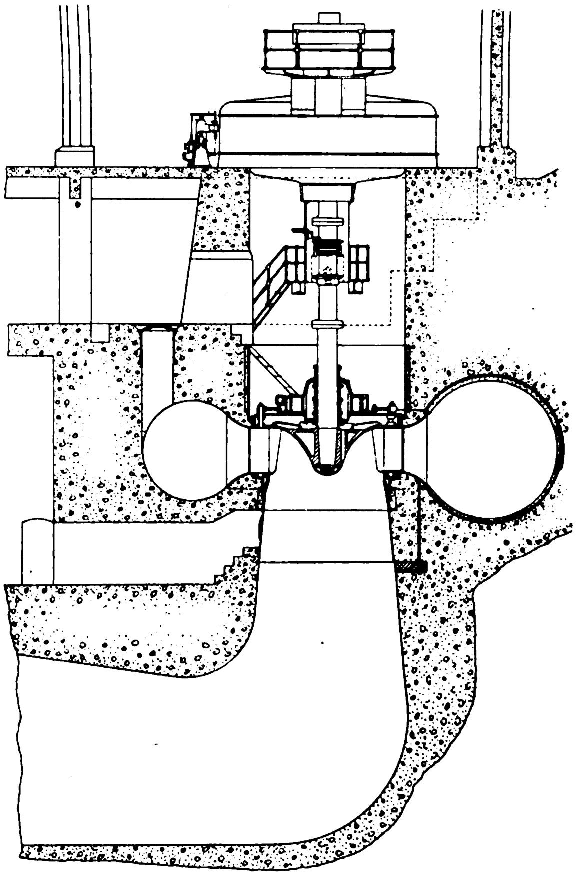

Fig. 16—Cross-Section of Spiral Casing Formed in the Concrete with Reinforcing Bars Attached to the Speed Ring Flanges

15,000-h. p., 68.5-ft. head, 112.5-rev. per min.

that recent experiments are proving the superiority of the open-hearth steel shaft as against the specially compounded alloy materials.

Guide Vanes

The trend of modern designs is strongly toward the cast steel guide vane having stems cast integral

and controlled by levers and operating mechanism placed outside of the water. Fig. 8 shows some of the guide vanes for the Siskiyou Electric Light & Power Company, 18,000 h. p., 125 ft.

The number of guide vanes is fixed with the same considerations as that fixing the runner vanes, that is, adopting only sufficient guide vanes to 'orm smooth

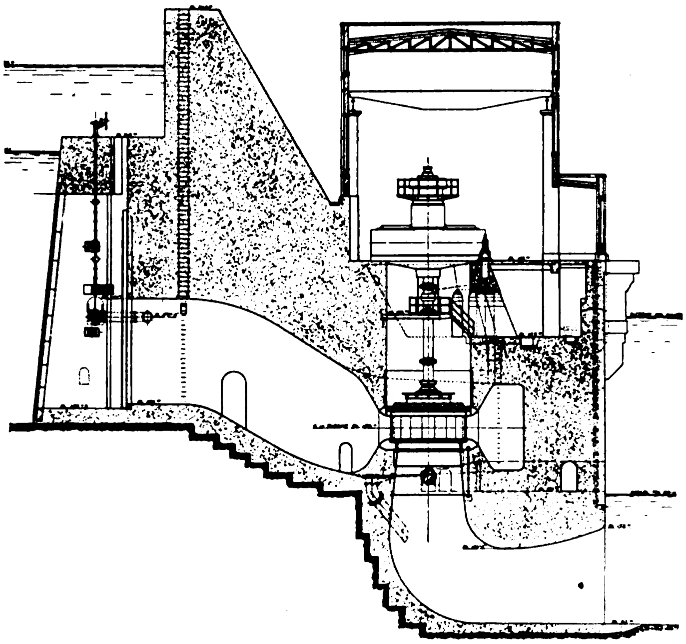

Fig. 17—One of Five Complete Allis-Chalmers Hydroelectric Units
Each 20,000-h. p. under 75-ft. head at 100-rev. per min.

passages so that the water will be delivered to the runner in as nearly one uniform whirling rotation as possible without too many guide vanes so as to avoid the too great accumulated vane surface resulting in friction losses. The favored number of guide vanes of this type seems to be twenty. The shape of the guide vane is that left to the individual designer. The writer has used the design of vane illustrated here many years with good success. The guide vanes are controlled by links and levers to one common shifting ring. It is essential that some adjusting device be interposed between each vane and shifting ring whereby the vanes may be adjusted so as to prevent excessive leakage in the closed position. The adjustable feature is particularly useful when the vanes are sprung due to obstructions lodging between two vanes when closing the unit down. Breaking links interposed between each guide vane and the shifting ring are essential, and that type of link should be used which may be readily replaced without unwatering the turbine.

Cast iron guide vanes, bronze bushed, such as shown in Fig. 9, connected by links to a shifting ring make a very satisfactory arrangement for open flume settings. An adjusting means should be inserted between each guide vane and shifting ring as in the former case.

A recent invention of plate steel guide vanes formed from one sheet of metal welded along one edge, has the advantage of having an unusually smooth surface, and of being easily repaired when distorted by foreign substances entering the wheel. It is particularly useful in low-head installations. The ideal control of the guide vanes and operating mechanism is that illustrated in Fig. 10, wherein the operating cylinders are fixed to the pit ring and operate directly through reach rods to the shifting ring. A very satisfactory arrangement is that wherein the operating cylinder is located on the main generator floor exerting its effort through a vertical shaft to cranks and levers connection to the shifting ring as shown in Fig. 11.

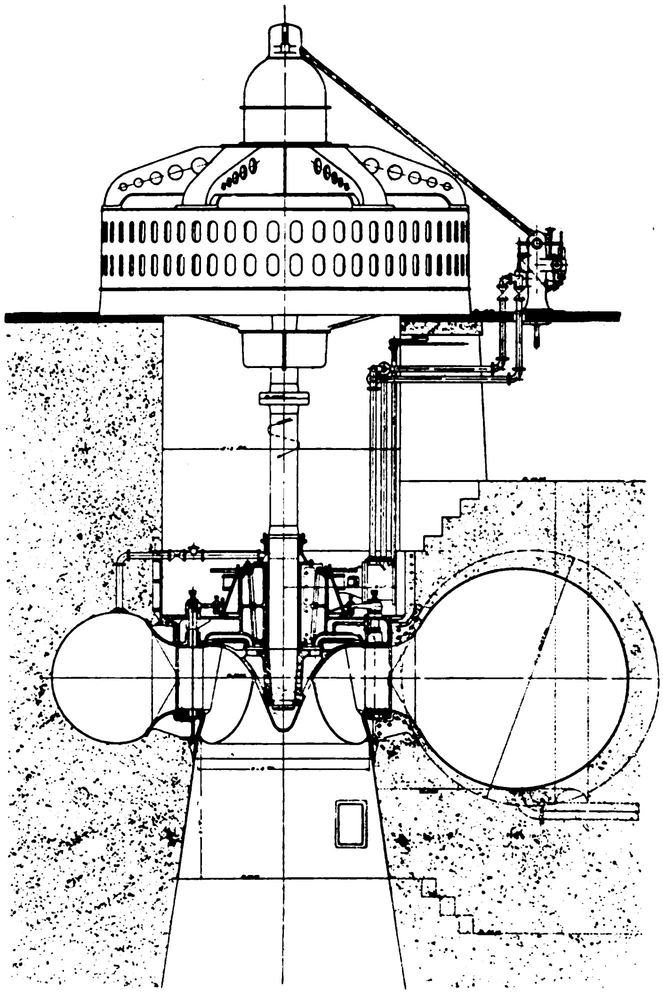

Fig. 18—Vertical Hydroelectric Unit with Imbedded, Circular Section, Plate Steel Spiral Casing
Governor flyballs mounted directly on main shaft.

Governors and Governing

In the case of poor speed regulation the governor is usually charged with the failure to perform, whereas actually the governor itself is only one of three problems entering into the governing of a waterwheel unit as set forth above. The function of the waterwheel governor in itself is the moving of the guide vanes a

proper amount in the proper time, and the readjusting of the guide vanes to the proper conditions of power and speed after the pressure rises produced by the movement of the vanes have been dissipated and conditions have returned to normal for that required power. The waterwheel governor has to perform more functions than any other type of governing apparatus, since it must move the gates to control the rise of pressure in the pipe line and the rise of speed caused by it.

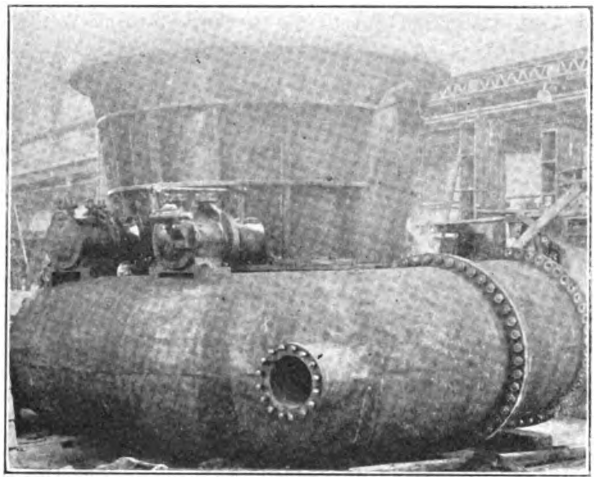

FIG. 19—11,000-H. P. VERTICAL-SHAFT TURBINE
Single-runner, cast iron, spiral-cased type, 360-rev. per min., 258-ft. head. Supporting barrel ready for generator.

A centrifugal flyball imparts motion to the center of a floating lever and the springs of the flyball are usually designed so that the governing mechanism is caused to operate quickly from wide open to closed position and vice versa when the speed has changed in the same time through a range of 20 per cent to 35 per cent of normal, this percentage selected depending upon the $W R^2$ of the revolving parts and the relative inertia of the water to be handled. After this sudden change of speed and motion of gates has taken place then compensation must take place to bring the speed back to normal. This is accomplished through a compensating dash pot introduced between a connection to the shifting ring and the end of the floating lever opposite that to which the regulating valve is connected. This dash-pot arrangement is so devised that for slow changes of load from no-load to full load the drop in speed may be zero or may be 2 per cent for parallel operation as per adjustment of the governor, but for quick changes of speed the gates can be closed or opened only by a change of speed from 20 per cent to 35 per cent as may be adjusted, thus introducing the time element, because the proper $W R^2$ will require time for the absorption of the uncontrolled energy.

Modern hydraulic governors are so sensitive that a change of speed of less than ¼ of 1 per cent will serve to move the gates to cause an adjustment of the guide vanes, and consequently the flow of water to compensate for the speed change. The conditions of inertia and $W R^2$ introduce dangerous factors into the regulation of the plant. These faetors are controlled through the time element of motion of the gates. This time element is dependent upon the reliable motion of the flyballs, consequently some means of reliable and effectively fixing the time of the flyballs with reference to the speed of the unit is very desirable in plants having bad conditions for regulation.

Fig. 11 shows a type of self-contained governor which is eminently suited for low-head open-flume plants. The particular governors herein shown are self-contained, having no interconnections; they have now been in operation seven years, and a recent examination of the plant showed that at no time has it been found advisable to have interconnecting piping between the governors.

Fig. 12 shows a directly connected flyball which has been used on a good many of the large plants. This type of flyball avoids the use of belts and the possibility of shut-down from their breakage, and also avoids the gears with the necessary small bearings on the horizontal jack-shaft.

Fig. 13 shows the governor stand for controlling the gates of the 37,500- h. p. unit of the Niagara Falls Power Company. In this particular design the operating fluid is supplied from a central oiling system. The operating fluid is water containing a percentage of oil.

INTEGRAL GOVERNORS

The latest advance in the art is that of the integral governor illustrated in Fig. 14, wherein it will be noted that the governor motion is imparted by flyballs

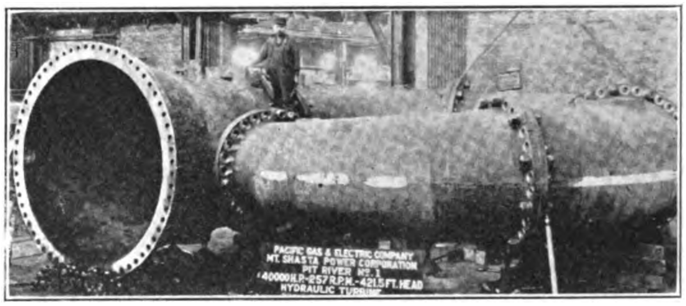

FIG. 20—CAST STEEL SPIRAL CASING
Having a thickness of three inches to withstand a head of 421.5 feet.

mounted directly upon the main shaft and the operating fluid is controlled by operating valves and governor mechanism located immediately on one of the operating cylinders connecting to the shifting ring directly through reach rods. The hand-control mechanism is located on the other operating cylinder. By means of this design we come back to the accepted practise in steam turbines, steam and gas engine design, wherein the governing mechanism is an integral part of the prime mover. The waterwheel governor has so many

functions to perform that it is necessarily complicated, and in the early development of the art the governors were made by companies separate from the waterwheel builders; consequently it came to be the accepted practise to consider the governors as a mechanism unto themselves. The present waterwheel governors, however, are so strong in design and reliable in operation that they do not necessarily have to be located

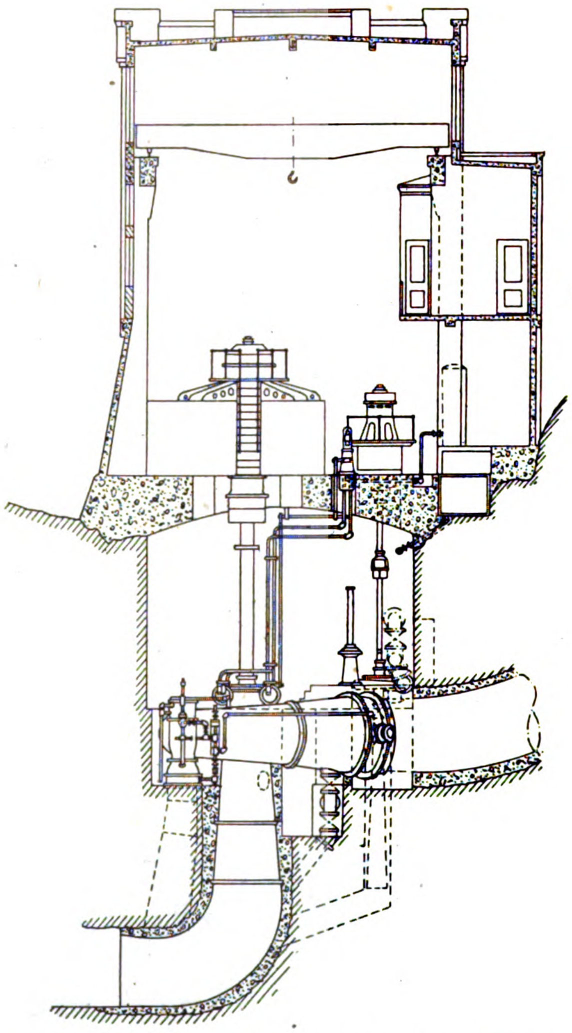

Fig. 21—Power House of Kerckhoff Plant of San Joaquin Light & Power Co.

Containing three units, each 15,000-h. p., 315-ft. head, 360-rev. per min. Butterfly valves, pressure regulators, curved draft tubes, and direct-connected flyballs.

on the generator floor immediately under the control of the operator, particularly since the unit may be controlled through a small synchronizing motor from the switchboard. The trend is toward the further simplification of the governor equipment and it is believed by the writer that we will in time come to the self-contained governor with no interconnection between the pressure systems of the several governors as is now frequently the case. Certainly the complicated central system with large sizes of piping required is not receiving the sanction of the buyers as much as formerly. A step in the right direction is the design of the Wateree Power Company, having direct-connected flyballs and the pump which provides the oil pressure for operating the governor driven through gears from the main turbine shaft, as shown in Fig. 15. In the case of the Mount Shasta Power Company the switchboard gallery is located above the main generator floor, and by adopting the integral governor the floor men are automatically placed on the turbine deck.

Turbine Casing

In low-head open-flume plants the casing is omitted but the walls of the flume are frequently shaped to form more or less of an open spiral so that the water may be directed smoothly to the runner. It is of prime importance that the water flowing to the guide vanes be kept free from eddies and whirls and as nearly an ideal stream flow as possible. It has been found and determined definitely that disturbed flow does increase the efficiency of a waterwheel unit, although the loss of head by that disturbed flow cannot be determined in the stream entering the unit. An analogous condition to that of disturbed water flowing through a runner is that of water flowing over a weir. Small eddies or cross currents in the stream flow approaching the weir, although so slowly and quietly as to be practically negative, and are certainly not sufficient to break the surface of the water; yet they produce breaks and notches in the weir crest several inches deep, when they flow over the weir. If such disturbances are occasioned in the flow over a weir, which is accompanied by such small surface disturbances, how much greater must be the action within the guide vanes and runner where the velocities are much higher, by disturbed conditions of flow in a pipe where the eddies and whirls may easily be many times that shown on the surface of the water back of the weir. The result of this disturbance has been definitely shown in the decrease of efficiency of the waterwheel.

The spiral casing affords the best means of conveying the water from the pipe line or forebay to the speed ring placed around the guide vanes. The spiral should be proportioned not exactly as per the decrease of the water as it passes through the annular opening through the speed ring to the guide vanes, but the casing should be kept slightly larger toward its smaller end. Water flows around an elbow at greater velocity on the short radius of the elbow than on the long radius of the elbow, and consequently, this higher velocity on the inner radius of flow is very much accentuated since the angle of flow is through 360 deg. in the spiral casing instead of 90 deg. in case of the elbow, consequently, as the velocity is increased on the inner portion of the spiral casing, the area of the spiral should be increased so as to reduce, if possible, the average velocity and consequently maintain the velocity at the inner radius of the spiral as nearly a uniform velocity around the casing as possible.

Concrete spiral casings of rectangular cross-sections

have been used in many plants with success, but the present trend in this connection is toward concrete spiral casings having circular cross-sections, with reinforcing rods in the concrete around this circular section, with either end of the reinforcing rod secured to the flanges of the speed ring. A concrete spiral casing of this type is illustrated by Fig. 16. Concrete spiral casings are suitable for heads up to 70 feet or 80 feet only when the superstructure of the power house is imposed on top of the spiral casing to avoid the tension in the reinforcing rods and in the concrete.

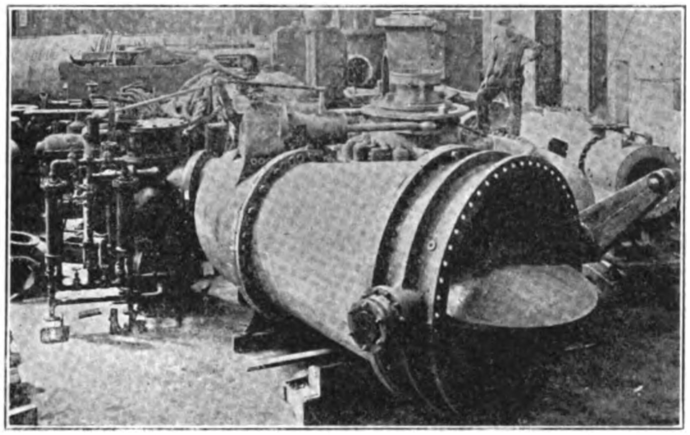

FIG. 22—SHOP ASSEMBLY OF 15,000-H. P. TURBINE UNIT
315-ft. head, 360-rev. per min.
84-in. butterfly valve, pressure regulator, and regulating cylinders.

A good design of power house, adopting concrete spiral casing reinforced in the manner above mentioned, combined with a section of the dam, is illustrated in Fig. 17. In this design the overturning of force the water against the upstream face of the dam is transmitted through the concrete to the top of the spiral casing and reacts to resist the upward forces produced by the pressure within the spiral casing. Fig. 18 shows a plate steel circular section spiral casing installed at the Lookout Shoals Plant of the Southern Power Company. The head obtained at this plant is 80 feet. This type of casing has been used very extensively during the last eight years on heads varying from 30 feet up to 215 feet. In the latter case the diameter of the inlet to the spiral casing was 11 feet and the thickness of the plate at this diameter was ⅞ inch. Larger casings with heavier plates are being contemplated for similar heads. The advantage of this casing is its cheapness in first cost, its resistance to sudden shocks and its ease of transportation.

Cast iron spiral casings are frequently employed, such as are illustrated in Fig. 19. This casing is made in two parts and the unit develops 11,000 horse power under 258 feet head at 360 rev. per min.

The cast steel spiral casing illustrated in Fig. 20, being built for the Mt. Shasta Power Corporation, embodies the latest improvements in high-head spiral casings. The waterwheel is equipped with twenty guide vanes, the casing has ten speed vane ribs, and the casing is divided naturally into five sections each with two speed vane ribs. The ribs are cast integral with the casing. Special provisions were used in preventing casting strains in the making of these castings. Each of the speed vanes are of a definite design decreasing in size around toward the small end of the casing and varying in angular relation to the casing to accommodate each particular speed vane to the flow of the water at that point.

There is no hard and fast line fixing the use of one type or the other of spiral casings but, usually, the configuration of the ground surface at the location of the plant determines the particular type of development best suited for the maximum development of efficiency, taking into consideration economy of construction.

VERTICAL VS. HORIZONTAL UNITS

The trend of modern design is toward larger and larger units and toward designs which will give maximum amount of power from the energy of the water available. This naturally leads to the single-runner, vertical unit because, as pointed out, the larger the waterwheel and generator, the more nearly in accord are the economical speeds of the two. The larger the waterwheel runner, the more difficult it is to place the runner with the shaft in horizontal position. The higher the specific speed of the runner, the greater the energy in the discharged water; consequently, the more important it is to adopt a regaining device which will return the maximum amount of that energy to the runner for effective development of power.

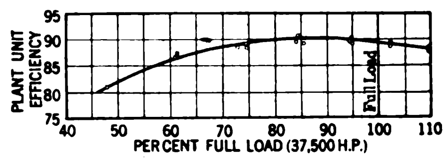

FIG. 23—CURVE SHOWING COMBINED EFFICIENCY OF ALLIS-CHALMERS TURBINE AND GENERATOR
37,500-h. p., 214-ft. head, 150-rev. per min.

CONTROL VALVES

A recent invention comprising snap rings disposed around the periphery of the disk of butterfly valves provides a means of making this type of valve substantially water-tight. This should bring this type of valve into more general use because of its great simplicity and reliability in operation.

Fig. 22 shows the butterfly valve constructed for the Kerckhoff Plant of the San Joaquin Light & Power Corporation, having a diameter of 84 inches and operating under a head of 315 feet. Note the simplicity of a valve of this type, and the small obstruction which the open wicket causes to the flow of the water through it.

Power House Setting

It is really a misnomer to say modern power house setting, because each power development requires a setting peculiar to its location, and that setting is modern only when there is brought to bear in its design experience gained on other power plants. One type of development, if we may call it such, is that exemplified in the Wateree Plant of the Southern Power Company, wherein the power house is made a part of the dam. At this location there was sufficient width in the river to place the power house as a part of the dam and thereby save expense. Another location of apparently similar conditions might necessitate a spillway of the full width from bank to bank which would force the development of possibly a new type of power house or the best of the existing types of power house.

The best power house setting can only be obtained by a careful analysis of all the factors, the aim being, as always, to produce a plant which will after years of operation prove the least expensive, considering not only the original investment, but the operating and depreciation charges.

Electrical Terminal Facilities

BY COMMANDER C. S. McDOWELL
U.S.Navy

THE other papers presented at this meeting deal with the application of electricity on shipboard. Proper terminals are closely allied with shipping and very necessary for its operation, and it is, therefore. the purpose of this paper to show in a general way the necessity of electrifying terminals, presenting to shipping men some knowledge of what can be done with electrical apparatus to simplify their problems, and to present to electrical engineers some idea of such shipping problems as concern terminals.

In considering the question of our American Merchant Marine, it appears probable that the subject of suitable terminals has not received the attention which it deserves. Transportation is the necessary means of conveying the products of the factories, mills, mines and farms to the consumer, and as we must look to the markets of the world for the customers of a certain part of our products, both raw and finished, every one who is at all concerned in the production of material in this country is affected by the efficiency of our means of transportation of products to the ultimate consumer, situated as may be at the ends of the earth. Transportation is as much a part of the cost of production as labor or material. Ordinarily, however, in thinking of transportation from our factories, mines grain elevators, etc., to the foreign purchaser, we consider only the necessity of getting the product to the seaport by rail or boat, and the shipping required to carry it across the sea. The great importance of the connecting link, the terminal facilities, required for the transference of products from the one system of transport to the other, was forcefully brought home to most of us during the war. The amount of material piled up on the Jersey Meadows, for instance, made many a manufacturer wonder at the insistent demand made on him to rush his orders for foreign shipment, and this congestion at our ports was not primarily due to the lack of ships, but to the inability to get the materials to the ships, and quickly loaded on them. Thus, if we assume that under the congested terminal conditions during the war, it took ten weeks for a ship to make a round trip, while with adequate terminal facilities the same ship could make the round trip in five weeks, it is seen that terminals are in reality the neck of the bottle and that the mere building of ships and doubling or quadrupling our merchant fleet does not increase our ability to transport freight in the same ratio.

To operate our merchant marine economically in peace time, and compete with other countries, it is highly important that the "turn around" should be cut down to the minimum. There is no particular purpose in providing economical propelling and auxiliary machinery on shipboard, if all the saving obtained by such improvements is eaten up by unnecessary delays in port, waiting to unload and load cargo.

We need fewer and higher skilled, better paid shipmen and dockmen with the very latest, speediest machines for loading and unloading. Such facilities both ashore and on board ship, combined with the higher skill of America in operating and caring for machinery is our chance to offset the higher wage paid our seamen, and put us on a competitive footing with our friends in the Atlantic or in the Pacific.

The time has now arrived when active steps must be taken toward constructing wharfage and warehouse facilities adequate for the use of our ever increasing Merchant Marine. Most cities have restricted their activities simply to the construction of piers, with little consideration for the development of adequate storage and freight handling facilities.

No standard layout can be established as applicable to all terminals, as the variables encountered are too numerous. Thus, the kind of cargo to be handled, (bulk, as coal, wheat, ore, etc., uniform package as

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Presented at the Joint Meeting of the N. Y. Section of the American Institute of Electrical Engineers and the Metropolitan Section of the American Society of Mechanical Engineers, New York, N. Y., January 28, 1921.

bagged sugar, or general cargo), determines the facilities that are required. In addition, the methods of receipt of cargo for ocean shipment and of distribution of the cargo from ships, whether by rail, by lighter, by truck, or storage in local warehouses, influence the apparatus required. Also, the types of ships docking at a terminal determine somewhat the mechanical facilities required on the pier.

The simplest method and the one allowing the most economical handling of freight is the one where standard ships run between two definite ports, always utilize the same terminals and carry only bulk or standard package freight. Under such conditions the special problem may be solved by installation of permanent electrically operated conveyers of different types, electric cranes, mechanical unloaders, etc., and cargo handled in much the same manner at ocean terminals as ore is handled on the Great Lakes. The above condition also permits the installation of all the cargo handling apparatus on shore and eliminates the present steam winch, which is notoriously inefficient, from the ship; it also, by the same elimination, puts the cargo handling gear where it is used practically continuously and removes this gear from the ship where it has been a large expense to install and keep in order, being used for a short time only at the end of each voyage.

Under such conditions, the ship becomes a freight carrier and is analogous in this respect to a railroad car or barge.

Unfortunately, the conditions as outlined above are seldom or never met with. A near approach to it, though, is the shipment of export coal. Up to twenty years ago the most efficient type of plant consisted of a pier with railroad tracks on two levels, the loaded cars running out on the high level, discharging their load at a height of some 40 feet above the water into the chutes which fed directly in the cargo holds. The cars then proceeded to the end of the pier where they were lowered by a platform elevator or a drop table, returning to the shore over the lower line of track, both lines being so graded that the cars traveled by gravity. The limitation in this system lay in the speed with which cars could be handled, and the capacity did not exceed 300 or 400 tons per hour. An objection to the system was the fact that a very large amount of rolling stock was tied up, it being necessary to have a full ship's cargo waiting on wheels at the pier.

About twenty years ago one of the above type of piers was remodeled in the following manner: At the shore end large hopper bottom bins were built which held an entire ship's cargo of coal. Through a tunnel under these bins, which were provided with gates in the bottom, there was run a 36-in. belt conveyer, which in turn fed a second conveyer, which ran the entire length of the pier. This conveyer discharged the coal at several points simultaneously, and provided a loading capacity of 800 tons per hour. This system also greatly reduced the number of cars operating between the mines and the pier, as each car was immediately released after dumping its coal into the storage bin.

Although other types of piers with gravity feed have been built in the past twenty years, the present trend is apparently toward the belt conveyer system, electrically driven. Thus, one of the latest coal piers built is the loading pier for the Baltimore and Ohio Railroad at Curtis Bay, Baltimore, at which the cars are dumped in the yard on shore on the tail end of the system of four parallel 60-in. belt conveyers, each of which discharges to the vessel by means of a large "tripper" consisting of a movable steel tower, which carries pulleys over which the belt turns back on itself to discharge its load.

The above is given as an example of what may be done in the loading of a uniform bulk cargo, in the case of coal piers; the proposition is simply one of loading; if unloading is to be provided for, an entirely different type of equipment is required, and in such a case for bulk cargoes, separate piers are usually provided. Unloading of bulk cargoes has not been brought to the same degree of efficiency, as a record on the Lakes of 2½ hours unloading for a 10,000-ton vessel, as compared with 23 minutes for loading it, will show. The Hulett "grasshopper" unloader is now in general use and consists essentially of a massive frame or walking beam, whose front end rests on the face of the dock, and the rear end on a slightly raised concrete wall. On this frame is a carriage moving backwards and forwards over the trough. The outer ends of the walking beam are legs which reach down into the hold; the whole mechanism being operated by one man. When a load of 15 to 20 tons is elevated by the bucket clear of the vessel, the carriage runs back on the main frame until the bucket is over the weighing hopper or trough and there the load is released. The weighing hopper moves only between the main legs of the machine. A cable runs along side of each track continuously and the movement of cars is taken care of by the cable. An operator pulls a lever on the mechanical clamp which is attached to the train and moves the train a car length for the next load.

The cheapening of the cost of unloading by the successive steps by which the process has been improved since 1880 is shown by the following:

Cost of unloading a ton of coal with wheelbarrows	$0.56
With Brown machine and shovelers	0.28
With Brown fast plants	0.12
With Hulett fast plants	0.04

Another method where efficient mechanical appraatus for loading and unloading may be employed is in the uniform package freight, which consists of coffee, sugar, seed, rice, paper in rolls, crates of fruit, bananas

in bunches, cotton seed cake, and many other commodities of similar character.

At the Port of New Orleans where bananas are unloaded in greater quantities than in any other port in this country, the handling of the unloading by mechanical devices has been developed until practically all of the bananas are now unloaded by machines. The general plan is to employ unloaders of a structural steel framework supported by railway trucks running on standard railway tracks set close to and parallel with the face of the wharf. The framework supports a double boom which can be adjusted into position over the hatchway of the ship. Over the booms constant running chains are installed which are equipped to carry several bunches of bananas in huge slings. The chain is lowered through the hatchway by means of the adjustable booms and after being placed into position the bananas are placed into this sling and removed from the hold to be deposited on a receiving table on the wharf. Trolley conveyers are utilized for distributing the bunches of bananas to refrigerator cars located on railroad sidings, running perpendicular to the face of the wharf, these conveyers having branches to each siding.

Mechanical unloaders of a construction similar to that given above have been designed for handling of miscellaneous cargoes and are installed, or being installed at some army bases. They consist of structural framework with double boom and constant running chain carriers similar to the one mentioned above. The plan in this instance is to carry small trucks loaded with miscellaneous cargoes. These trucks are fitted with small wheels so that when they are deposited on the wharf or in the storage rooms they are automatically released and can be wheeled to any position or location desired. For carrying material within the warehouse, it is planned to carry these same trucks automatically on overhead trackways and have them automatically deposited wherever wanted. This type of apparatus is reversible and can be used for both loading and unloading ships.

In the case of bags and bales, not very much progress has been made in the utilization of continuous movement apparatus, although unloaders of the conveyer or continuous chain type have been developed and installed in some cases. The electric crane has been developed to such efficiency that it is probable that continuous movement unloading machinery would have a hard time competing with it. Bags and crates unloaded through hatches are lifted in the rope sling by boom or crane and deposited on the wharf deck for handling. In some cases, however, conveyers have been built with a movable section, permitting it to be extended to the deck of the ship where bags, barrels, etc., are fed to slings which lower a sling full at a time into the hold. In case of unloading, the slings are used to take the freight from the hold.

Speaking generally, it is easy to provide mechanical handling facilities for bulk cargo, or for package cargo, when the latter is uniform. The difficult proposition is to provide facilities for miscellaneous cargo, and as a rule, the ships leaving our ports carry a mixture of almost everything from kegs of nails and sacks of grain, to steel rails and crated automobiles, and for such a mixture there is no adequate system of mechanical handling.

In this connection it may be noted that the stevedore is required not only to handle the freight from the dock to the vessel, but to so place it and secure it in the vessel, that stability and center of gravity may remain just right, and that the cargo itself may not shift and be injured by the constant movement of a vessel in an ocean voyage.

For the handling of such miscellaneous cargo, an electric crane is most essential and it appears preferable that the cargo be handled directly into the ship's hold with the crane without the use of the ship's booms. The question of the number of cranes to be provided at the pier depends to a great extent upon the character of the pier itself; if room and facilities are available for feeding cargoes to each hatch, then there should be sufficient cranes to work all hatches. It may be noted that in new basins at Hamburg the cranes are spaced every 100 feet. When the cargo is to be distributed in part or in whole by lighters from a pier, a desirable arrangement is to provide cranes on dolphins on the offshore side of the ship for loading and unloading to lighters, at the same time the cargo is being handled on the pier. Incidentally, in connection with electric cranes, it should be noted that electric heaters are desirable for the comfort of the operator, in cold weather.

It is not the purpose of this paper to go into the design of the pier itself, but it is presumed that a marine pier or terminal will be provided with sufficient space to handle both incoming and outgoing cargo without confusion.

On the wharf, itself, means are required for handling the loads for conveyers or crane hoists to and from the ship, and the old method which is common today on many of our wharves is the use of the hand truck. For short movements the hand truck cannot properly be dispensed with, but for most movements on the wharf, the electric truck or tractor with trailer, or the continuous movement, portable piler with trailer, can and should supersede the hand truck, and eliminate many of the men now required to handle cargo. These trucks, or tractors, are usually of the storage battery type and have demonstrated their thorough usefulness.

For handling cargo on the pier, an overhead trolley hoist, either of the monorail type or of the double track type, commonly used in large factories, has been developed.

For stacking freight at the terminal a tiering machine has been utilized which allows not only much more rapid tiering with the elimination of most of the

manual labor, but also allows tiering to much greater heights.

In some cases two-decked piers have been built in order to save space, and in order to keep incoming and outgoing freight separated without moving the ship. This form of pier usually requires a connection between the two decks and involves elevating and lowering from one deck to the other. These movements are accomplished by electric freight elevators, by continuous movement parcel elevators, etc.

For moving freight cars at the terminal, electric locomotives, either of the trolley type or storage battery type, may be provided, or electric gypsies installed. For handling ships' lines, and moving ships at the pier, electric winches can be used, and in addition, electric winches of the permanent or portable type can be utilized for whips, either for handling cargo on the ships or for handling on the pier itself.

To sum up, the following are some of the electrical apparatus and devices which are available for use at terminals: Cranes; conveyers, belt or chain type; trucks; tractors with trailers; tiering machines; pilers; mechanical unloaders; winches, permanent or portable; freight elevators; overhead trolley hoists; locomotives.

The electrical supply at the terminal should be of the same voltage and kind of current (d-c. generally) as that in use on board ships which are to be handled. This will allow the ship to receive electric current from the pier for the ship's purposes, and the ship generators can be shut down while at the dock, so that all overhauling on the ship's steam and electric system can be made at the same time as freight is being discharged and received. This should materially reduce the average "turn around" time and allow the ship's main and auxiliary machinery to be given a thorough examination, and overhauling, while in port.

It is believed that modern port terminals offer a good electric load, which central stations should endeavor to develop in order to increase the efficiency of our terminals, as well as to improve the load factor of central stations.

It has been stated that it is extremely difficult to provide efficient mechanical handling apparatus which can take care of all types of miscellaneous cargo. Economical progress in the handling of ocean freight can be greatly assisted by the construction of large warehouses on shore in which various kinds of miscellaneous cargo can be classified and handled by suitable machinery. It is possible that in the future terminal companies may be developed to act much as the railroad and other transportation companies, so that freight may be consigned to them as one link in a through bill of lading, from the producer to the customer. It is conceivable, under such conditions, that special piers will be utilized for different classes of products, the terminal company classifying freight from the mainland, and segregating it at the piers for handling such material, and having ships assigned for carrying that particular type of products only, and making shipments in shipload lots of one class of material. Such a procedure would, undoubtedly, materially reduce terminal charges and permit the operation of our Merchant Marine under more efficient conditions.

NOTE: In preparing the above, the following sources were consulted: "Ports and Terminal Facilities," McElwee; General Electric Company, Westinghouse Electric and Manufacturing Company, The Lampson Company, Robins Conveying Belt Company, etc.

CIRCULAR ON TELEPHONE SERVICE

A circular on Telephone Service has been published by the Bureau of Standards, Washington, D. C.

The product which a telephone company sells is service but from an analytical standpoint the service as a whole must be divided into its elementary characteristics which are peculiar to the nature of the service and to the manner in which it is rendered.

Service in general is considered in the introductory section while descriptions of the telephone plant and its operation are given in sections which respectively consider developments of the telephone art, equipment of manual systems, equipment of automatic systems, outside line construction, and telephone traffic. These are followed by the section on the principal elements of telephone service.

Attention is especially directed to the section entitled "Principal Elements of Telephone Service." Here are considered those service characteristics which are outlined in the determination of the grade of service and thus there is furnished a basis for future work along the lines of service standards. The elements are considered in groups each having common service relations and the most important factors involved in each case are enumerated and their relations to the grade of service are explained.

A section on the subject of public relations has been included to cover those phases of telephone service which receive attention by regulatory commissions both federal and state. Plant extensions, abandonment of service, physical connections, accounting, valuation, rates, rate schedules, contracts, collections, and discrimination have been considered. A conclusion is drawn regarding the subject of service standards. The rapid and extensive development of the telephone industry is indicated by statistics given in the form of an appendix.

The circular, No. 112, may be obtained from the Superintendent of Documents, Washington, D. C., at 65 cents per copy.

Technical Committee Annual Reports, 1920-1921

(Concluded from page 595 of JOURNAL for July, 1921.)

PROTECTIVE DEVICES COMMITTEE

To the Board of Directors:

Several years ago it appeared that the work of the Protective Devices Committee would be conducted to better advantage if it should assume that the Committee would be largely reappointed from year to year and that it might undertake investigations which could not be completed within any one fiscal year. Since that time it has practically lost all interest in the fiscal year except for the purpose of making its annual report in accordance with the Constitution. The investigations of its sub-committees has continued from year to year and on several occasions the sub-committees have presented their report in the form of a paper before the Institute.

At the present time the work of several sub-committees has not progressed to a stage where they are ready to present any lengthy reports in the form of papers, so that the present reports can be considered as progress reports. Several of the subjects under investigation by the Committee are discussed in the following summary.

Current Limiting Reactors

By F. E. RICKETTS

In view of the papers presented at the Annual Convention last year on this subject, this sub-committee has been able to collect but little data that would be of interest.

Certain papers presented at last year's Annual Meeting went into much detail in explaining the possibility of high-voltage stresses between turns of reactors during abnormal conditions of operation. Failures that had occurred in certain forms of reactors where bare conductors were supported by concrete were attributed to this cause. Since certain contributors to the discussion of these papers disagreed with this statement and, as it has since been fairly definitely determined that some of the failures were due to mechanical weakness rather than to high voltages, it seems proper to call attention again to this subject. This type of reactor has since been strengthened by adding more concrete supports for the conductors and it appears that the trouble has been thereby overcome.

Certain tests to determine the rupturing capacity of oil circuit breakers have been made that indicated that reactors while reducing the maximum current may subject circuit breakers to additional strains by tending to prevent the circuit from being interrupted at the zero value of current, which is the point at which a circuit-breaker usually interrupts the circuit in the absence of reactance.

System Troubles

By A. A. MEYER

From replies to a request for data on system troubles experienced during the year 1920, information was received from a number of the larger companies.

Some of the replies include numerous cases of improper functioning of relays, but which were not serious in affecting the system. They could hardly be classed in the same category the committee considered for investigation. Moreover, several of such cases were cited without any word of explanation as to the possible cause of improper functioning. It would take considerable time and study to analyze all such cases of false tripping and draw any valuable deductions. I believe the committee should confine its attention first to the cases which seriously affect the system as a whole.

Among the most noteworthy cases, the following performances and factors are of interest as affecting the system as a whole. Relays are reported as functioning too promiscuously on a transmission system. Instead of the relays close to the source of trouble functioning and isolating the trouble at once, these relays fail for various reasons, and as a consequence, relays elsewhere on the system operate and shut down large sections, if not the entire system. The reasons for the relays failing to isolate only the section in trouble are such as, incorrect connections, improper settings and shortcomings in the relays themselves when called upon under abnormal conditions on the system, accompanied usually by low voltage. Several cases were cited where low pressure, delayed reverse power relays from functioning in the time that was intended. Some transmission systems comprise a series of sections with graded settings, the relays in each section being set a trifle above or below the settings on the neighboring sections. Where the series contains many sections the increments in the settings necessarily have to be small to avoid too high a setting on the section close to the source. In some cases the increments are too low and due to slow circuit breaker operation, isolation of a fault is sometimes obtained by cutting out sections in additions to the desired one. In other cases the increments are too large and a fault occurring in a section close to the source is held connected too long to a system, and as a result the initial fault drags so hard on the generators as to throw them out of step, and a real system disturbance follows. Some desire has been expressed for the need of current limiting feeder reactors to avoid such a heavy drag on the generators due to a fault near the station. System troubles have also arisen out of small initial troubles in several cases due to circuit breakers of inadequate interrupting capacity. Duties on circuit

breakers not infrequently outgrow their capacity on fast growing systems. It is quite essential that the capacity be checked up occasionally and compared to the duty which might be expected.

Another noteworthy factor responsible for system troubles comes through the practise of providing low-voltage releases on power house auxiliaries. In several cases it was reported that low main bus pressure caused the plant auxiliaries to drop off, thereby making matters much worse. The practise of providing such protection on plant auxiliaries needs careful reconsideration in, no doubt, many cases.

In the above, reference has been made only to some of the short-comings of relay schemes. Outside of these, troubles have also arisen through electrolytic lightning arresters. One company reports several cases of fire, some of which were quite serious, due to the arrester itself failing through some slight mistreatment. The hazard is greater than perhaps realized by many users of electrolytic arresters.

The above are the main items of interest brought out in the replies to the committee's request for a report on system troubles. No doubt there are several other cases of system trouble still unreported. It is hoped that some of these will be reported at a later date.

Lightning Arresters

By F. L. HUNT

The sub-committee on Lightning Arresters has given consideration to the lightning arrester subject, with a view to determining what might be done by the members of the Protective Devices Committee to increase the usefulness of lightning arresters as protective devices.

Many engineers have questioned the necessity for using lightning arresters on all circuits because the results obtained from their use have been more or less unsatisfactory, due in part to inherent defects in the designs of the arresters, and in many cases on account of misapplication of the equipment that is available.

In order to obtain information regarding the present practise of engineers and operating companies in the use of lightning arresters, and to obtain as much information as possible regarding the defects which have developed in the commercial arresters as produced today, and the unsatisfactory experiences which have been had in their use, a short questionnaire was sent to members of the Protective Devices Committee and to a few other operating engineers. A summary of these data is given herein.

Twenty-nine copies of the questionnaire given below were sent out and twenty replies have been received up to the present time. We were also able to arrange a conference with Mr. R. A. Paine, who has collected data on lightning arrester practise to be used by the Overhead Systems Committee of the N. E. L. A., and to make use of those data so far as they applied to the questions under consideration by our committee. The sub-committee has not had an opportunity as a whole to discuss or consider the data which have been collected. It is recommended that such consideration be given, however, either by the sub-committee or by the main Committee, in order that the greatest benefit may be obtained from these data. The questionnaire sent out was as follows:

1. What general type of lightning arrester would you recommend for feeder circuits of 1000-kw. capacity or greater, leading from a generating station or important substation?

(a)	10,000 volts.	(c)	66,000 volts.
(b)	33,000 volts.	(d)	150,000 volts.

2. Under what circumtances, if any, do you think it advisable to omit lightning arresters entirely from circuits of the above description?

3. How many lightning arresters would you recommend and what general class of arrester for a substation from which power was being distributed by six 22,000-volt overhead circuits? (Consider only 22,000-volt side of substation).

4. On what class of circuits of 10,000 volts and above would you advocate the use of horn gap lightning arresters?

In addition to the points raised above, the committee is especially anxious to get the fullest possible expression of your opinion as to the objectionable features in the principal types of lightning arresters used today on voltages of 10,000 and above.

We believe the work of the Protective Devices Committee in studying the uses and improvements desirable for protective devices can make progress on the lightning arrester problem by obtaining the reasons for the adverse opinions which exist. If you are willing to give us, therefore, the facts or experiences on which you base any objections you may have, it will be of great service to the committee.

The replies to this questionnaire indicate that the general practise is remarkably uniform. A very large majority of the engineers replying to this questionnaire agrees in its recommendations on each of the points raised. There are a few notable exceptions, however, and a few opinions expressed which vary quite widely from the majority of opinions, but which are given by men of such broad experience and in such responsible positions, and are based on such definite cases of experience that we believe it advisable to give especial attention to these statements. Since we are all familiar with the general practise on these points as is evidenced by the majority of opinions expressed in the answers to these questions, we are perhaps warranted in giving especial attention to the exceptions to the rule.

The answers to Question No. 1 were as follows:

(a) 16 — Oxide film
15 — Aluminum cell
1 — Condenser resistance with horn in parallel to the condenser
1 — Compression chamber
1 — Horn gap with water resistance

(b) 16 — Oxide film
14 — Aluminum cell
1 — No arrester
1 — Horn gap with water resistance

(c) 14 — Oxide film
13 — Aluminum cell
1 — Bennett type
2 — Horn gap with water resistance
1 — No arrester

(d) 13 — Oxide film
13 — Aluminum cell
1 — Bennett type
1 — Horn gap with water resistance
1 — No arrester

It should be noted in the above answers that the majority of those recommending oxide film recommend the aliminum cell also.

Answers to Question No. 2 show 12 who believe there are no cases where arresters should be omitted entirely. There are several who are willing that they should be omitted at small substations or on short and unimportant lines, or at points not subject to lightning. One omits arresters for 30,000 volts and over, one for 66,000 volts and over, and two on 150,000 volts and over. One omits arresters where apparatus of modern design is installed.

The answers to Question No. 3 are as follows:

13 — Recommend one arrester for each circuit, of which ten recommend the oxide film.
5 — Recommend one arrester on the bus.
1 — Recommends one arrester for each two circuits.
1 — Recommends one arrester for each transformer bank.

The answers to Question No. 4 are as follows:

11 — Do not recommend in any case the use of horn gap arresters.
4 — Recommend their use on unimportant circuits from small stations.
3 — Recommend their use with resistance in series on circuits of 12,000 volts or over.
1 — Recommends their use on 22-kv. circuits from substations.
1 — Recommends their use on all circuits over 10,000 volts.
1 — Recommends their use on customer's small substations.

Of the comments on the objectionable features of lightning arresters practically all the remarks were applied to aluminum cell arresters. The disfavor toward the horn gap is shown by the small number that recommends its use. Specific objections to this type were mentioned by a few, as follows:

One objection made which applies to nearly all classes of arresters is that the spark gap used in most designs reduces very much the protective qualities of any arrester, provided the arrester could be designed without a spark gap.

Referring to the aluminum cell arrester, six object to the fire hazard of the aluminum cell, eight object to the care and excessive attention required to keep the aluminum cell arrester in operating condition and in a condition to be a protection to the line, and one states that the mechanical features are poorly designed and do not stand up in service.

Extracts from some of the letters are as follows:

Operation erratic and protective qualities questionable.

Disturbances are set up by the discharge of horn gaps when used without resistance.

Do not stand up under service.

As to the objectionable features of the principal types of lightning arresters used on voltages of 10,000 volts and above, I presume by "principal types" you refer to aluminum electrolytic type and the oxide film types. My principal objection to these types of arresters is that they are dependent for their operation on somewhat obscure phenomena depending upon certain characteristics of the materials of which the arrester is constructed, these characteristics involving the action of films of very minute dimensions. In my opinion a multiplicity of elements of so minute a nature cannot be depended upon to provide the strength and reliability necessary for a lightning arrester.

* * * * *

I have witnessed a number of years of successful operation of large power plants with lightning protective equipment substantially as above, and during these years, at different times and places, both electrolytic and oxide film arresters have been tried out with indifferent success. I believe that all of the electrolytic arresters involved in this evolution have now destroyed themselves, while the horn gap-water barrel combination is still successfully performing its functions.

About two years ago I purchased 16 sets of oxide film arresters for 12,000-volt circuits. Only one of these sets, so far as I know, has had a discharge pass through it and this set was practically destroyed on this occasion. There was present at the time, it is true, an abnormal condition of high dynamic voltage, but I am positive that a water barrel horn gap type of arrester, as above suggested, would not have been injured. It is my opinion that better protection at much less cost can be obtained by means of home made apparatus of the type suggested than by spending large sums of money for hair-trigger types of arresters based on fine haired theories and obscure chemical reactions.

* * * * *

Past experience with lightning arresters makes it difficult if not impossible, to justify their expense particularly so at the high voltages. Where companies have made consistent efforts to get definite data in regard to apparatus failures with and without arrester protection, the results occasion distrust as to the effectiveness of the protection afforded by arresters. One of the companies affiliated with the .... Company has maintained a thorough record of this nature and finds that failures have occurred more frequently and have effected larger apparatus at installations protected with arresters than on other installations of lesser importance which have not been so protected. This is true both at 100 kv. and at 66 kv.

* * * * *

While it cannot yet be said that the omission of lightning arresters at the higher operating voltages is to be generally recommended, in view of the evidence at hand serious consideration should be given the subject and the justification for each new installation decided upon its merits.

* * * * *

We have kept careful records of apparatus failures on our high-voltage lines, and when we first began building these lines in 1910 we were of the opinion that it would certainly be necessary to have arresters to protect the apparatus. Our experience with arresters, however, soon demonstrated that it would be a cheaper thing to have spare transformers than it would be to repair the very large and expensive aluminum cell arresters. We finally, in 1912, stopped using them entirely, and our expense of maintenance has been materially reduced. We probably pay some penalty in first cost of rather expensive transformers, but we feel that we are justified in getting the very best and highest type of transformers and dispensing with the lightning arrester, and feel that from the standpoint of service and the standpoint of economy we have made a gain.

From an analysis of some of the reports on lightning arresters, and from a study of their designs, it appears that in order to secure the best protection, one of the paths through the lightning arrester should be a high current capacity path, that is, a path that will allow a large current to flow at the time of lightning discharge. If such a path is provided, the arrester will have a

lower maximum voltage across the terminals at time of discharge than will be the case if the discharge capacity or rate of discharge is limited by the insertion of a resistance. It is possible that with a resistance in series, the maximum voltage will be higher than the break-down potential of the apparatus or cables which the arrester is intended to protect.

In general, transformers intended for a normal operating pressure of about 25,000 volts will withstand somewhat higher potentials than underground cables for the same working pressure. This is due to the fact that transformer windings are submerged in oil which has a high dielectric puncture value, and in addition, the end turns of transformers are generally built with extra insulation which will withstand higher voltages than the remaining turns in the transformer, and as the frequency of lightning discharges increases with their potential, it is the end turns in transformer windings which are subjected to the greatest strains at the time of lightning discharges. This means that for the protection of underground cables which are connected to overhead lines, arresters should be used having a high current capacity at time of discharge such as the aluminum cell or the oxide film arrester, while transformer installations, for supplying individual customers, which are connected directly to the overhead lines may be protected by types of arresters which have a lower discharge capacity and therefore a somewhat higher maximum potential across the arrester at time of lightning discharge.

Circuit Breakers and Switches

By H. R. Woodrow

Your sub-committee has analyzed the replies to the questionnaire on oil circuit breakers which was sent out in cooperation with the Apparatus Committee of the N. E. L. A., and Power Switchboard and Oil Circuit Breaker Section of the Electric Power Club. A short abstract of the general conclusions from these replies was published in the March issue of the A. I. E. E. Journal.

The Apparatus Committee of the N. E. L. A. has prepared a detailed summary of these replies which will be presented before the N. E. L. A. at its annual meeting in Chicago on June 1, 1921.

From the discussion following the presentation of the paper on "Present Day Practise Limitations of Oil Circuit Breakers" at the midwinter convention, the following additional comments are made:

Rated Voltages. The present standards of the A. I. E. E. specify that oil circuit breakers shall be given a dielectric dry test consisting of the application of 2¼ times the rated voltage plus 2000 volts between the live parts and ground for 60 seconds. Although the questionnaire did not indicate in any way that such a test would not give adequate insulation it was brought out in discussion that some operating companies are purchasing apparatus of a voltage rating higher than the system voltage on which the apparatus is to be used.

It is recognized that the dielectric test recommended by the Standards of the A. I. E. E. must meet the requirements of average systems. It must also be recognized that systems not protected by adequate lightning arresters and systems of very large capacity may be subjected to voltage rises due to surges or lightning that will exceed the insulation values required by the Standards of the A. I. E. E. Taking those points into consideration, it is not recommended that these Standards for dielectric tests be changed. However, for systems that have characteristics, or inadequate lightning arrester protection, such that higher insulation is required, the present practise of selecting apparatus of the next higher voltage rating is endorsed.

Rated Continuous Current Carrying Capacity. As little trouble has been experienced from overheating of oil circuit breakers when carrying normal rated current, it is evident that if proper precautions are taken for alinement of current-carrying parts and ventilation of compartments, little trouble would be expected from this source.

Rated Momentary Current Carrying Capacity. As a few cases of trouble were reported from this source and as a result of the tests made by the New York Edison Company, it is recommended that oil circuit breakers be given a short-circuit current rating for periods of both one and five seconds.

Rated Interrupting Capacity. It appears from results of the questionnaire that the operating companies may require ratings on duty cycles other than the present recognized standard as given in the paper by Messrs. Hewlett, Burnham and Mahoney. There is considerable difference of opinion regarding the point of ending this duty cycle, the allowable condition of the breaker at that time, and what is considered satisfactory operation of the breaker.

It has been impossible to answer satisfactorily these questions at this time, and it is therefore suggested that this matter be given careful consideration by the next year's sub-committee.

General Comments. The subject of oil circuit breakers as reported by this committee was intended to cover the field of station breakers which would have to rupture large amounts of power rather infrequently, and is not intended to cover the subject of circuit breakers such as used in control equipment where they should be capable of interrupting full-load current a large number of times per hour for long continued periods and not be required to interrupt heavy short-circuit currents.

The activities of this sub-committee have been confined this year entirely to the subject of oil circuit breakers, and it is suggested that next year's sub-committee consider the question of rating and ruptur-

ing capacity of fuses, both of the power class and potential transformer class, in addition to following up the study on limitations of oil circuit breakers.

Schemes of Relay Protection

By E. A. HESTER

It is the function of the sub-committee on Schemes of Relay Protection to act as a clearing house for all information on protective relay schemes and to present this information in such a form that it will be an authoritative record of the progress of the art. The results of the first questionnaire, which was presented to the Institute in June, 1919, covered only such schemes as were recognized as standard because of their successful operation.

A second request for information was sent out February 24, 1920, in order to obtain an authentic record of schemes which are being, or have been, tried out and proved successful or abandoned as worthless.

In pursuance of the program outlined in the report of the Committee last year, the members to whom the six Geographic Sections of the United States and Canada were assigned have submitted to the Chairman answers to the request for information from practically all the operating companies to whom these requests were sent. Much interest was manifested by the various companies in the work of the sub-committee and, while some of the replies were delayed because of the pressure of other work, it may be said that, in general, they responded very promptly.

In replying to this request practically every company has given a description of all relay schemes which it has used, both standardized and otherwise. In many instances the information on the standard schemes is much more complete than that which was given in the reply to the first questionnaire, thus adding to the completeness of the sub-committee files and further substantiating the conclusions given in the previous report.

On account of the very large volume of material contained in these reports the sub-committee has not yet been able to coordinate it into the form of a report. A great amount of classification and compilation will be necessary in order to reduce the information to a report of practical value, and the sub-committee is now engaged in this task. It is planned to present this report in a meeting of the Institute some time next winter.

In addition to the various schemes described in the June 1919 Institute PROCEEDINGS several companies have reported the successful use of other schemes and not a few reported certain schemes still on trial or tried out and abandoned. It is not possible to describe these in this brief resume, though casual mention of two or three of those now in successful operation will be of interest and will serve as an indication of the general trend in protective work.

A new pilot wire scheme has been used very successfully over a period of approximately three years by one large company. This company's system has become so complicated that considerable difficulty was experienced in determining relay settings and in securing selective action of relays.

The new pilot wire scheme was therefore developed in order to reduce the number of relays requiring progressive settings and to simplify and reduce the settings on other relays where this could not be used. It is known by its originator as the Balanced Differential Relay System, and depends for its operation upon an unbalance of currents in the differentially wound relay coils. Such unbalance in the case of a fault on the line results from partial or complete opposition of e. m. fs. on the pilot circuit. On a through fault the e. m. fs. are additive and equal currents flow in the relay coils, but in opposite directions, so as to neutralize. Under normal conditions no current flows through the relays or in the pilot circuit.

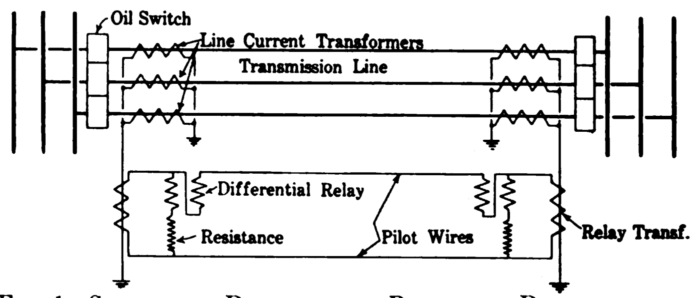

FIG. 1—SCHEMATIC DIAGRAM OF BALANCED DIFFERENTIAL RELAY SYSTEM

This scheme is illustrated in Fig. 1 and as may be seen, only two pilot wires are necessary. It is very simple, and on short lines compares favorably in cost with other standard installations. The cost will increase, however, as the line becomes longer because of the necessity of pilot wires.

In case this scheme is used on ungrounded systems where a ground is not involved in the fault it will be found necessary to use a modification employing three pilot wires. This is not illustrated.

Another company reports the successful use of a modification of the balanced or cross-connected relay scheme in which an additional double-contact differential current relay is used. This scheme is applicable to parallel lines, the lines being paired off and balanced against each other. In the case of three lines the current relays on the third line are given special settings. The differential relays are not used to trip the circuit breakers but to reduce the time settings of the relays on the faulty line to approximately one-half that of the relays on the other line. Thus the faulty line of the pair is selected and the other line is left with adequate relay protection. Advantage for this scheme, over the instantaneous balanced scheme, is claimed in that the circuit breaker is not called upon to interrupt the initial rush of current. If it is desired however, the differential relay can be connected to trip

the circuit breaker direct. A diagram of the connections used is shown in Fig. 2.

The cost of this scheme is the same as that of a standard installation except for the additional cost of the differential relay, which is practically the same as that of the standard induction type current relay.

One very interesting installation of selective ground

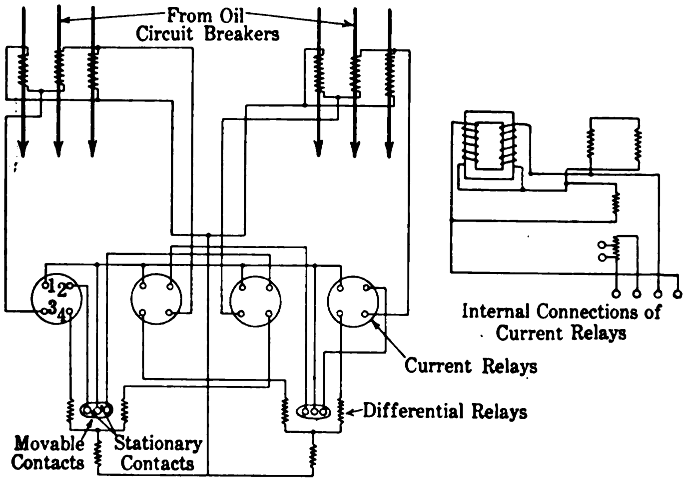

Fig. 2—Schematic Diagram Showing Differential Relays

relays is reported. All operations up to the date of the report had been successful but the time of service was not considered sufficient to prove definitely its value. The scheme was installed with the expectation

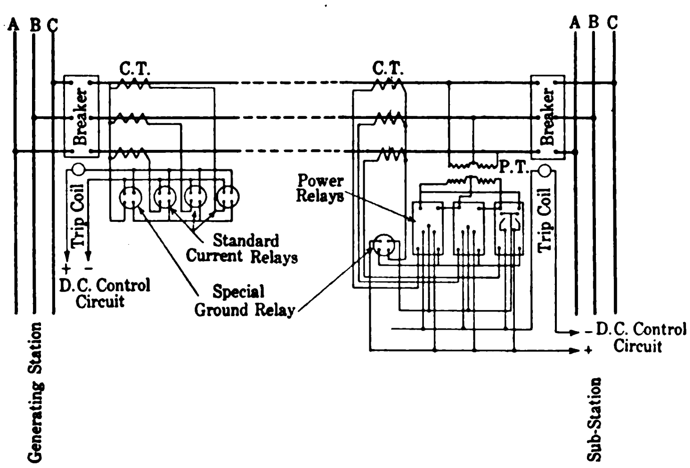

Fig. 3—Schematic Diagram Showing Use of Ground Relay

that faults of slow development to ground would be cleared at an earlier stage than is possible with phase relays, thus preventing the trouble from being communicated to nearby lines and preventing the system from being subjected to severe shock.

A special relay wound for low operating current and having low energy requirements is inserted in the current transformer neutral lead on standard current and power relay installations. When used with current relays this ground relay trips the circuit breaker direct, while with power relays at the substation end it is arranged to short-circuit the over-current phase relay contacts, thus leaving the power relay to discriminate as to direction of power flow. The principle of operation is obvious since current will flow in the ground relay only upon the occurrence of a ground. Therefore, in the case of phase to phase short circuits the operation of the phase relays is not interfered with. This may be clearly seen by referring to Fig. 3.

The cost of this scheme exceeds that of the standard installation only by the additional cost of the ground relay which is practically the same as that of the standard type current relay.

The above developments would indicate that the general trend is toward the selection of defective lines by means of the fault or trouble current rather than by relying altogether on the use of progressive time settings and current settings on the basis of the total current. As systems grow larger and more complicated progressive settings necessitate maximum time intervals which are so high as to be impracticable and the need for adequate schemes which do not require progressive settings has become a necessity as well as a convenience. While no scheme has as yet been developed which can be universally applied and which will obviate the necessity of progressive settings, the manufacturing and operating engineers are to be commended for their efforts toward this end. Results which have recently been obtained give promise of a closer approach to the ideal means of protection.

It is the aim of the sub-committee on Schemes of Relay Protection to preserve an accurate record of the developments and operations of the various protective schemes, which records will be available to the operating and manufacturing companies under the Committee rules. It is to be hoped that the service of this sub-committee will play some part in preventing duplication of effort among engineers and foster a gradual tendency toward the standardization of protective relay schemes and devices.

D. W. Roper, *Chairman.*

IRON AND STEEL INDUSTRY COMMITTEE

To the Board of Directors:

During the past year, the important part played by electricity in the Iron and Steel Industry has in no wise diminished, although the extent of the growth of electrification has been relatively small as compared with recent years, due to the almost complete cessation of expansion in the industry, beginning in the latter part of 1920.

Periods of business depression, with the coincident demand for low production costs, invariably bring into prominence the wasteful and imperfect producing element of each plant, and the present period is no exception. Furthermore, the present necessity for finding ways and means of meeting low-priced competition in foreign markets adds emphasis to the searching out of inefficient units. As heretofore, the more

general application of electric power is usually an important factor in the strengthening of the weak links, so that at this time, a large amount of electrical installation, particularly in the line of replacing steam engines in the drive of main rolls, is recognized as essential and is only waiting upon the devising of means of financing.

Much progress has been made in the most recent installations of reversing mill drives and of adjustable-speed equipments for the lighter finishing mills. Control equipment of all kinds shows marked tendencies toward simplification, although at the same time making possible considerable reduction in the human element in the industry.

In common with all industry, the iron and steel plants of many parts of the country will, on resumption, be confronted with the power problem and much attention is being directed toward the development of dependable low cost sources of electrical energy. Again, in steel plants of size, the transportation of the raw and semi-finished materials within the plant limits is responsible for an important percentage of the total production cost and investigations are being directed to the possibilities of the reduction of this item by yard electrification.

Your Committee cooperated in every possible way with the Pittsburgh Section and Meeting and Papers Committee of the Institute in arranging for the Institute Meeting in Pittsburgh on April 16th in joint session with the Association of Iron and Steel Electrical Engineers. One of the papers was prepared by D. M. Petty, a member of the Committee, and other members contributed discussion. The meeting was a very successful one and served to continue the close and harmonious relations so desirable between these two national societies.

William F. James, *Chairman.*

TRANSMISSION AND DISTRIBUTION COMMITTEE

To the Board of Directors:

The Cable Research sub-committee appointed jointly by your Committee and the Underground Systems Committee of the National Electric Light Association continued its work during the year.

As the standard specification for paper-insulated lead-covered cables, completed by the sub-committee last year, met with such general favor, it was suggested that the sub-committee prepare similar standard specifications for rubber and varnished cambric insulated cables.

For the reason that considerable work along these lines had already been done by committees of other technical organizations but particularly because the Institute had recently joined the American Engineering Standards Committee it appeared that the entire subject of cable specifications should be brought before that body.

A conference was called in New York on February 2nd, 1921 by the American Engineering Standards Committee and after a thorough discussion of the many considerations involved it was unanimously decided that the unification of cable specifications for wires and cables for other than telephone and telegraph use should be undertaken under one general plan covering substantially all the more important uses. This work is now being carried out under the auspices and in accordance with the rules of procedure of the American Engineering Standards Committee.

In the matter of standardization of cable ratings, some work has been done by the Cable Research sub-committee and further investigations are in progress. Similar work is under way in England under the supervision of the British Electrical and Allied Industries Research Association.

The published report of that Association as well as the investigation so far conducted by the Cable Research sub-committee show very clearly a lack of agreement as to the maximum permissible operating temperature of paper insulated cables.

Until an agreement can be reached on this very important point it will be impossible to arrive at any definite conclusions regarding cable ratings. It may be possible, however, to prepare a tentative rating for cables of various sizes and voltages to show the permissible current for various maximum temperatures and under definite physical conditions, leaving it to each user of cable to determine, for the present, the maximum permissible temperature for his own cables.

At the Midwinter Convention of the Institute, one session under the auspices of the sub-committee on Wires and Cables, was devoted to the discussion of cable ratings and papers were presented by a number of manufacturers and users of paper-insulated, lead-covered cables.

A number of those participating in the discussion expressed the opinion that the maximum limit of 85 deg. cent. is too conservative for low-voltage cables in which the dielectric losses are small and several believed that the limit should be placed at 105 deg. cent. which is the limit for fibrous insulation in electrical apparatus.

It is expected that steps will be taken during the coming year to initiate investigations which will result in a definite determination of this maximum permissible temperature.

Tendencies in Overhead Transmission and Distribution Practise

Transmission. The present tendency in transmitting electrical energy is decidedly toward the use of increased voltages. This is particularly so in considering transmission problems, which problems are now involving the transfer of larger blocks of power over longer distances than were formerly considered practical and economical.

The interconnecting of various load centers to take advantage of diversity in demand is receiving the careful attention of transmission engineers. Transmission lines operated at 150 kilovolts have been in service for a number of years and materially higher voltages are now considered. At least one line, that of the Southern California Edison Company, is under construction for 220 kilovolts. This line is being built in connection with the Big Creek No. 8 hydroelectric development and will form part of a system for transmitting over a distance of 240 miles, about 750,000 h. p. at 220 kilovolts.

It would appear that the limit in transmission voltage will be governed by the successful development of conversion and switching apparatus to control the large amount of energy requiring such voltages. Practically all the earlier transmission lines were constructed on steel supports. There is a tendency today, however, particularly in the West, to construct such lines on wood supports, using spans up to six hundred feet in length.

The quality of insulators now available is apparently much better than that obtainable prior to about 1915. This applies particularly to suspension insulators, and while suspension insulator practise since 1915 has shown improvement in performance under operating conditions, a sufficient length of time has not elapsed as yet, to measure this improvement. The design of pin insulators has undergone a decided change in recent years; as now designed they are more substantial, and their performance has been considerably improved. The tendency today apparently acknowledges the greater necessity for a more careful selection, dependent on load characteristics, climatic conditions and also a higher electric factor of safety than was former practise. Every effort is being made to increase the margin of puncture over flashover voltage. Arcing horns and similar devices are coming into use, so designed that no part of the insulator or conductor will be damaged during flashover, by the heat of the arc.

The effect of heat cycles, cement expansion, and similar characteristic changes in insulators is being studied in order to reduce to a minimum the so-called insulator depreciation. The results obtained thus far cannot be said to warrant any radical change in the physical design.

Apparently, overhead ground wires for lightning protection are being discontinued in many locations except where such wires have been installed to provide additional stability to the line structures, dependence being placed entirely upon the successful performance of the lightning arresters connected to the line.

The practise of carrying on maintenance and repair work on live transmission lines seems to be gaining in favor, special tools and equipment having been designed for changing insulators, carrying on new construction work and making repairs to both the line and its accessory equipment.

Aerial cable operated at voltages up to 26,000 has been installed through thickly settled communities for transmission purposes. This field seems to provide a possible solution to many problems involving the transmission of large blocks of power, through thickly settled territories, which heretofore has been considered possible only by the installation of an underground system.

Distribution. It would seem that no great change is to be expected in the 2200-4000 volt distribution system, so generally used at the present time. To provide for the rapidly increasing demand for electric service, additional substations are being installed, fed by aerial or underground transmission lines at relatively high voltage, from which substations the lower voltage primary circuits radiate.

The diverse character of the loads now being connected is resulting in the practise of dividing distribution systems into distinctively lighting and power service. It is common practise to construct power circuits at a higher primary voltage than the lighting circuits, connecting to the power circuit large motor loads, electric furnaces, welders, and similar types of utilization equipment; and as such equipment is usually of low power factor, special attention is being given to the development of power factor corrective apparatus in order that the entire capacity of such feeders will be available for distribution purposes.

The banking of transformers where the loads are congested, is now being generally considered, it having been demonstrated by a number of installations, that not only the power loss is materially reduced but the investment cost in transformers, copper and other similar items is materially lowered.

The greatly increased loads now commonly distributed, together with the large capacity of many of the systems is necessitating the complete redesign of much of the line switching and protective apparatus.

Probably the most recent distribution problem is the connecting of the loads in the more scattered or rural districts. The development of the so-called "farm lines" to reach this class of service has been very rapid. Electric service is a necessity to the modern farming community and its connection is resulting in the development of distribution circuits of 13,000 volts, more or less, constructed in a substantial manner but without the refinements of city construction. Such service is becoming available in practically all sections of the country. Extensions twenty-five to thirty miles in length feeding from fifteen to twenty customers are becoming common.

Tendencies in Underground Cable Practise

Higher-Voltage Cables. Better knowledge of the characteristics of impregnated paper insulation has made it possible to manufacture cables for operation at voltages much in excess of those formerly standard.

Three-conductor paper-insulated cables are now

being manufactured to operate at 33,000 volts whereas in the past 25,000 has been the maximum voltage commonly used with this class of cable.

During the year one of the largest central station companies ordered cable to be operated at a voltage higher than any heretofore used in this country. In Chicago there will be installed during the year about thirty miles of three-conductor cable intended for a normal working pressure of 33,000 volts. This cable will have sector shaped conductors each of 350,000 cir. mils, with 19/64 in. insulation around each conductor and 7/64 in. outer belt; the thickness of the lead will be 9/64 in. The over-all diameter will be about 2.95 inches, so that it can be installed in a 3½ inch duct. This cable will be used for two tie lines between a new generating station and one of the older generating stations which is near to the center of distribution.

It is also possible by reverting to single-conductor design to manufacture cable for operation on circuits rated at 60,000 or possibly 100,000 volts. This increase in voltage at which underground cables can be operated is an important advance, as high voltages have long been used on open wire circuits and in many cases the inability to construct cable of corresponding voltages has been a serious disadvantage. There will be many instances where high-voltage cables can be used to advantage in eliminating the necessity of extra transformations.

It is understood that the 60,000-volt single-phase feeders of the St. Gothard line in Switzerland has recently been placed in service, 30,000 volts being impressed on each single conductor cable.

Larger Cable Sizes. The necessity for using larger sizes of conductors has further increased the demand for sector cables on account of their smaller over-all diameter.

Two-conductor *D*-shape sector cables of 1,000,000-cir. mil and 1,500,000-cir. mil cross section are being used to a large extent on Edison d-c. three-wire circuits. The principal reasons for using this type, instead of the concentric type formerly employed, are the greater ease in splicing and the better balance of the resistance between the two sides of the three wire system.

Dielectric Losses. The subject of dielectric losses in cables is recognized as being important, but on account of the material reduction in the dielectric losses in cables as at present manufactured, the subject is not so often overstressed as was the case when the matter was first generally discussed. It should also be noted that cable properties are largely interdependent and that undue development of one characteristic may result in the sacrifice of some other equally important feature.

There is now available, cable which will not have more than 0.75 watt dielectric loss per foot of cable when operating at the maximum temperature allowed by the Institute Standards. Cables having dielectric losses within the limits shown in Fig. 1 will be found satisfactory.

Hochstadter Cable. Hochstadter Type *H* triplex cable in which the insulation of each single conductor is covered with an electrically conducting foil (usually of copper) and the three individual conductors assembled without any belt insulation, is in successful operation at high voltage.

Two companies have recently ordered three-conductor cable of the Hochstadter type for operation at about 25,000 volts. One of the companies ordered only sufficient cable for a portion of the line and the remaining cable was of the ordinary type with the insulation divided between the conductor and the outer belt. In the other case the entire order was for cable of the Hochstadter type but the manufacturer, at the request of the Cable Research sub-committee, made up a short length of the usual type three-conductor cable for a comparative test, this cable being made of the same materials and manufactured at the same time as the Hochstadter cable.

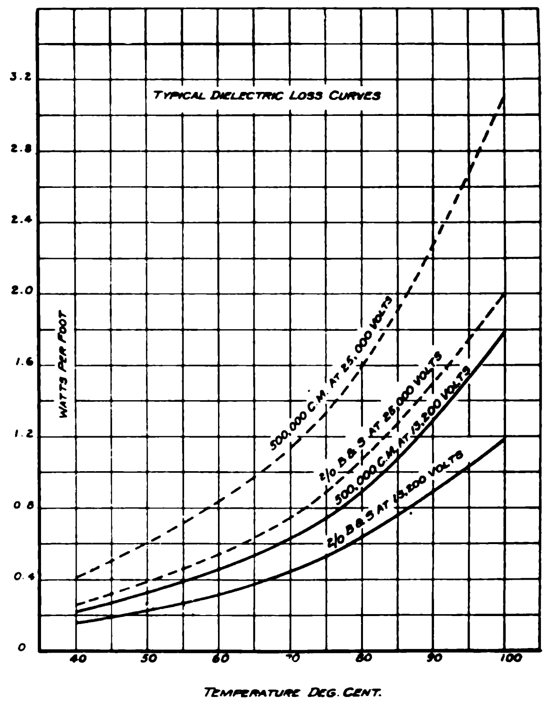

Fig. 1

As a result, the Committee has available the two sizes of Hochstadter cable to compare with the same sizes of cable insulated in the usual manner and has arranged for comparative tests of the merits of the two types of cable. A number of the larger operating companies, and the National Electric Light Association have contributed to the fund necessary for making these special investigations, the result of which should be available during the coming year.

Crystallization of Lead Sheath. Though the method of applying the lead sheath to underground cables has

changed but little in many years, there has recently come to notice a number of cases where the lead sheath has crystallized. This is not a new condition but in the past it has been comparatively infrequent. There have been a number of cases where cable shipped for a considerable distance showed signs of defective lead on arrival at its destination while other instances of similar character have been noted in the sheath of cables that were subjected to vibration after installation.

There is evidence of a direct relation between vibration and crystallization of the lead sheath, but it has not been definitely determined whether crystallization is hastened by improper methods in manufacture. It has been suggested that in many cases crystallization has been caused by localized impurities, or by the lead having become too cold in the die.

Power Cable Testing. Power cable testing practise is at present divided into four important branches:

1. Factory research and routine tests.
2. Independent laboratory tests.
3. Factory inspection and acceptance tests.
4. Field or installed tests.

1—*Factory Research and Routine Tests.* Factory research and routine has in recent years been stimulated by the demands of users for cable of higher quality, suitable for operation at increased loads, higher temperatures and higher voltages. Research work by progressive manufacturers has resulted in greatly improved product in all respects. It has also indicated most forcibly the need of improved routine tests in order to check materials and processes so that uniform high quality may be insured at all stages of manufacture. If the routine factory tests are properly planned and carried out during manufacture a consistently uniform product may be turned out, which need be checked only occasionally by special laboratory tests on the finished product. It is obvious therefore that the selection of materials and their handling during manufacture are the most important features of cable manufacture.

2—*Independent Laboratory Tests.* Independent laboratory tests have been carried out, at the request of both consumers and manufacturers. The results have been of great value from the standpoint of all interests for the following reasons:

a. Standard methods of testing have been formulated.

b. Advance information has been secured by consumers and manufacturers alike, which has in some cases resulted in manufacturers realizing the desirability of having their own laboratories equipped for test and research of similar nature.

c. General information which has been given out by such laboratories has shown a great lack of uniformity in the product of some cable manufacturers. This non-uniformity appears to be due to lack of knowledge as to how the component parts of a cable must be handled and tested during manufacturing processes.

3—*Factory Inspection and Acceptance Tests.* It is the practise of many users of power cables to carry out inspection at the factory before cables are accepted for shipment. Some also inspect during the process of manufacture as far as permissible without unfair inquiry into manufacturing secrets. This practise, which appears to be growing rapidly, keeps the manufacturer on the alert because his ultimate profit depends upon the acceptability of his product with a minimum number of rejections.

4—*Field or Installed Tests.* Many power cable users make regular tests after installations to detect injury during installation, and inadequate or faulty jointing. These tests vary from insulation resistance tests only, to complete high potential, insulation resistance, conductor resistance and capacitance tests.

In some cases it appears that unnecessarily severe tests are made which may result in injury to the cable. The test of service is undoubtedly the best of all. Any test which will detect incipient faults due to handling or installation is all that is reasonably required in addition to the factory tests and the test of time.

The safe loading of cables requires a knowledge of the characteristics of the cable location. Test to determine their characteristics are not, strictly speaking, cable tests, but they are of equal if not greater importance. This subject is being studied in this country as well as abroad and some preliminary results have been published in the technical press.

General. The Committee has called attention in previous reports to the reduction in dielectric loss at relatively high temperatures. Routine factory tests inaugurated by some manufacturers have made it possible to predict with accuracy the dielectric losses in the finished cable, which constitutes an important step in the production of cables uniform in this respect. One of the most important results not inconsistent with uniformly low dielectric losses is uniformity of dielectric strength, which has been noted to a considerable extent. The Committee does not think it proper, however, to refer more specifically to routine tests as they are largely the result of factory research.

There appears to be little of importance to report with respect to new methods of testing cables with high voltage, either in the factory of field, with the possible exception of the use of d-c. devices such as the Kenotron. This device appears to have possibilities of great importance and, as used experimentally by at least two utility companies, appears to fill a long-felt want for a light and portable apparatus for cable testing, and requires but a very small amount of power or capacity for its operation.

Attention is called to the possibility of paper-insulated cables breaking down under high-voltage tests but followed by immediate rehealing of the puncture.

This rehealing is usually temporary but may persist long enough to deceive in a test of stated duration. It is therefore essential that these "spits" be recognized and the test repeated until they have been eliminated.

The practise of testing faulty cables for fault locations has undergone no material change, the devices used being divided into two principal classes, one depending upon the principle of bridging, the other upon the exploring coil with signaling current.

Various mechanical tests are made on cables and cable dielectrics with which most engineers are familiar. One of particular interest is the so-called bending test on paper-insulated power cables. This test is carried out for the purpose of determining the likelihood of a cable being injured by handling during manufacture or installation.

Protection of Cable Systems. The increasing frequency of trouble on low-voltage (less than 550-volt) systems and the consequent danger of communication to other circuits has necessitated a great deal of attention being given to the problem of segregating the circuit on which the trouble originates.

On account of the probable resistance of the fault being sufficiently high to limit the flow of current, at this low voltage, to a value possibly not more than the normal load, it is impossible to get the desired protection by the use of fuses. For this reason some companies have omitted the fuse, while one company fearing an extended burn-out of this class of cables has provided each feeder conductor with a remote-controlled circuit breaker at the service end of the feeder designed to open when the feeder is in trouble.

These circuit breakers do not open from overload but have a trip coil that is connected to a pressure wire in such a way that, if the pressure wire comes in contact with either the lead sheath or the main conductor, the coil will become energized and open the circuit breaker. There is also provision at the station whereby the operator can, by closing a small switch, put current on the pressure wire to trip the switch.

With higher-voltage distribution cables, around 3000 volts for example, there is no difficulty in providing fuses that will carry normal load and blow under short circuit; but in this class of service the problem is to provide a fuse which will successfully open the circuit. For this reason a number of engineers recommend against the use of fuses on underground systems of this voltage.

When we consider still higher voltages of the order of those used for transmission, no attempt is made to use fuses underground. However, the majority of underground troubles originate on this class of cables and it is extremely important that every precaution be taken to prevent trouble starting in one of these cables from communicating to others. For accomplishing this, ducts should be separated by an adequate wall of fire resisting material, such as is obtained by laying fiber tubes in concrete so that the ducts will be separated by a continuous wall of concrete about one inch thick, except near the manholes where the separation should be increased to give a maximum separation at the end of the ducts. This extra separation at the edge of the manholes is advisable on account of the danger of communication of trouble from one cable to another at this point where the protection to the cable is apt to be least. The importance of protecting cables in manholes will be evident when it is considered that more than one-third of the failures in the higher-voltage cables occur in splices alone and a large percentage of the remaining failures also occur in the manholes.

Concrete continues to be the most popular form of protection in the manholes. It is not only a good protector against fire but it is also a better conductor of heat than other forms of protection. Owing to the effect of heat in decreasing the resistance of the insulation of high-voltage cables, it is extremely important, especially with cables constructed a few years ago, to avoid excessive temperatures in the duct line. This applies not only to heat dissipated by the cables themselves, but also to that produced by other sources, such as steam pipes and exhaust steam. There have been many instances during the last few years of serious troubles due to high temperatures produced by steam. Where it has been a case of exhaust steam or a local steam pipe it has been comparatively easy to overcome the trouble by changes in either the duct line or the point of exhaust, but where the heat has been experienced at many points due to an extensive steam heating system, changes that would be necessary to remedy the trouble have been too expensive to undertake.

Review of Papers Submitted During the Year

Insulators. In the May, 1920 issue of the Journal W. D. A. Peaslee contributed an article on *High-Tension Insulator Porcelain.*

This paper reviews the progress made in the ceramic field in the solution of the insulator problem. Procelain used in the manufacture of high-tension insulators must meet certain requirements as to mechanical strength, ability to resist sudden changes in temperature, porosity, homogeneity, and temperature coefficient of resistivity. The author gives a brief discussion on each of these requirements and the progress that has been made in the development of a suitable porcelain. A brief discussion is also given regarding the possibility of the deterioration of seemingly perfect porcelain being intimately connected with the Piezo electric qualities of quartz crystals.

In the June, 1920, issue of the Journal the same author discusses *Factors Controlling the Design and Selection of Suspension Insulators.*

Attention is called to the factors entering into the design and operating behavior of suspension insulators and the problems to be solved in designing a suspension insulator to overcome the objectionable features shown by experience to affect seriously the operation of the insulators in service. Factors to be taken into consideration in the selection of suspension insulators for a given condition are given and a brief discussion of the general trend of future developments is presented.

F. W. Peek, Jr., presented an article in the July 1920, Journal reviewing the duties of the line insulator at voltages above 100 kv. and comparing them with the duties imposed by the lower voltages in order to predict the reliability of future high-voltage

lines as compared with those at present in operation and pointing out what changes, if any, are necessary in present practise. While unimportant at the lower voltages, the uneven division of voltage on the different units of a suspension insulator becomes of increasing importance as the voltage is increased. Quite complete data are given on the phase of the investigation dealing with voltage distribution and the successful correction of the uneven voltage distribution by means of an antenna shield from the line. The author believes that with the very high voltages at present being considered, insulator troubles will probably be less frequent than with present voltages.

Operating Performance of Insulators on a 45,000 Volt System by H. B. Vincent in included in the January, 1921, JOURNAL.

This paper presents a method for the recording of insulator performance and shows how such a record enables one to know what service the insulators are giving and what one may expect provided the records have been kept over a sufficient period of time. The data presented refers entirely to pin type insulators and has been gathered from actual records kept by a power company. There is included an analysis of the data obtained from this company's report showing the performance of insulators on the various lines from 1914 to 1919 inclusive.

H. J. Ryan and H. H. Henline contributed an article appearing in the July, 1920, JOURNAL dealing with the quantitative relations which exist between the maximum and average voltage unit-duties in line suspension insulators made up of units in common use. The results obtained from a number of tests conducted by the authors to determine these relations on insulators of single and double strings with and without static shields are discussed in detail. From their investigations the authors believe that suspension insulator unit in common use can be satisfactorily employed for the makeup of insulators for 250-kv. lines.

Surface Leakage as a Factor in Insulator Design by T. M. Feder is discussed in the September, 1920, JOURNAL. The author calls attention to the various factors influencing surface resistance and the different methods by which this resistance may be increased. It is shown that the most economical way of decreasing the leakage is the addition of properly proportioned corrugations on the underside of the flange or skirt. Typical computations are given, showing the approximate increase in resistance to be expected when corrugations are added.

Overhead Transmission and Distribution. The 150,000-Volt Transmission Line of the Knoxville Power Company is described by Theodore Varney in the June, 1920, JOURNAL. The author discusses problems encountered in the design and construction of this line and the solution of these problems are described.

The conductor is of aluminum reinforced with steel and the longest span is 5010 feet long, which the author states is the longest single-conductor span in the world at the present time. A detailed description of both the standard and long-span conductors is given toegther with a summary of the points covered by the specifications drawn for the purchase of the standard suspension and anchor insulator units.

The July, 1920, JOURNAL includes an article prepared by D. M. Jones on *Power Factor Correction on Distribution Systems.*

After a review of the causes and disadvantages of low power factor, the writer discusses various methods of eliminating this condition. The methods provide for the use of the unity power factor synchronous motor, the phase modifier, the overexcited synchronous motor, the synchronous condenser, and the static condenser. The advantages, disadvantages and comparative costs of each type of apparatus are discussed.

P. O. Reyneau and Howard P. Seelye prepared an article which appeared in the October, 1920, JOURNAL on the *Economic Study of Secondary Distribution.*

This paper analyzes and evaluates the factors in the design of the secondary system which lend themselves to such definite analysis and presents the results as aids in the determination of the most economical design for a system. The derivation and application of equations and curves used for the determination of the most economical voltage drop, transformer spacing, transformer size and wire size under theoretical conditions are presented and discussed. Curves for practical conditions are then worked out for use of the designing engineer.

Cables. R. W. Atkinson prepared an article which appeared in the September 1920, issue of the JOURNAL on *The Current Carrying Capacity of Lead Covered Cables.*

After discussing the temperature rise in cables and their surroundings the author describes a method of determining the current-carrying capacity of cables based upon their temperature rise. Data are given whereby the current-carrying capacity of lead-covered cables can be calculated on the basis of thermal limitations. Carrying capacity as limited by voltage drop or economical considerations is not considered. The article shows how further data can be applied as these are determined.

An appendix contains some numerical examples illustrating the use of the data and in addition a chart by which it is possible to determine graphically, for given conditions, the carrying capacity of three-conductor paper and varnished-cloth cables installed in conduits.

C. W. Davis and D. M. Simons presented an article on *Maximum Allowable Working Voltages in Cables* appearing in the January, 1921, issue of the JOURNAL

This paper discusses methods of calculating stresses in triplex cables and gives examples of calculations made. Tables are given for determining maximum voltage stress in single triplex and type *H* cables. From calculated stresses the authors obtain a solution for the size of conductor which will produce a minimum stress for a given core diameter. The determination of the maximum possible operating voltages for given limits of stress and outside diameter is then described. From the limits worked out in this article it is the conclusions of the authors that for the high-voltage cables of the future the ordinary three-core form cable will be used as heretofore up to 30,000 volts, type *H* cable up to 50,000 volts, and three single-conductor cables having conductors made with a hollow fiber core for 50,000 volts and above.

At the mid-winter convention in February, 1921, James A. Cook presented a paper dealing with *Measurement of Relative Eddy Current Losses in Stranded Cables* describing a method which will insure accurate measurements of eddy current losses in stranded copper cables on a comparative basis. Results of tests are shown both for the measurements and the reduction of eddy current losses.

CONVENTION PAPERS

The following papers have been submitted and accepted for presentation at the Annual Convention at Salt Lake City:

Long Distance Transmission of Electric Energy by L. E. Imlay.

Voltage Regulation and Insulation for Large Power, Long-Distance Transmission Systems, by Frank G. Baum.

Voltage and Power Factor Control of 66,000-Volt Transmission Lines Connecting Two Generating Stations, by Raymond Bailey.

A Solution of the Porcelain Insulator Problem, by E. E. F. Creighton and F. L. Hunt.

Modern Production of Suspension Insulators, by Edwin H. Fritz and George I. Gilchrest.

Voltage and Current Harmonics Caused by Corona, by F. W. Peek, Jr.,

Transformers For Interconnecting High-Voltage Transmission Systems or For Feeding Synchronous Condensers from A Tertiary Winding, by J. F. Peters and M. E. Skinner.

Some Transmission Line Tests, by W. W. Lewis.

The Operation of Large Interconnected Systems, by L. L. Elden.

E. B. MEYER, *Chairman.*

LIGHTING AND ILLUMINATION COMMITTEE

To the Board of Directors:

The Lighting and Illumination Committee considers that along with the other Technical Committees, it can render a special service to the Institute, by securing papers which relate to subjects within the scope of the Committee and which will be of particular interest to the members of the Institute. The three excellent papers on street lighting distribution presented before the Chicago meeting last year illustrate this point. Following out this general thought, the Committee held a meeting early in the year for the purpose of considering what activities could be undertaken during the current year.

The results of this meeting of the Committee may be summarized as follows:

1. That it would be of value to members of the Institute for the Committee to start the accumulation of data relating to productive intensities in industrial plants, that is, to the question of intensities of illumination in the industries best suited to effective production. This data could well cover the question from the standpoints of the relations of illumination to factory production, to accidents and to reduced spoilage. The Committee felt that it might not be practical to attempt to secure papers on this subject this year because of the incomplete nature of studies which have been and are being made along this line, but it is hoped that in the near future papers may be secured on several particular aspects of the problem such as those relating to opthalmology, psychology, physiology, accident prevention, scientific management and production records.

2. The Committee felt further that it may be possible to secure a paper at some time in the near future dealing with glassware for lighting auxiliaries, such as that used with street and commercial lamps. A paper on this subject did not materialize during the current year but the Committee feels that a general summary of the glassware situation would be of considerable practical value.

Although neither of the foregoing plans of the Committee has taken definite form during the year, it is believed that the formulation of these suggestions has, in itself, been an item of progress and that it may lead ultimately to certain very valuable papers.

In addition to an effort to gather papers, the Committee feels that it may also render a service of value to the Institute by carrying out the intent of the resolution of the Board of Directors of May 11, 1921 through the preparation, as part of the annual report, of a brief summary of progress of the art in the lighting and illumination field. In the present report, reference is made to some of the more important features of the year's progress without any effort to make it complete in detail. Very full notes on the detailed progress and developments in this field are published each year as a Progress Report by the Illuminating Engineering Society. The following notes cover some of the more interesting developments which have been noted by the Committee and by the technical press during the current Institute year:

DEVELOPMENTS IN THE LIGHTING FIELD

Use of Incandescent Lamps. It is interesting to note at the outset that the estimated sale of incandescent lamps in 1915 amounted roughly to about 110,000,000 whereas in 1920 it was estimated that 230,000,000 were sold. These figures indicate that the lamp business has practically doubled in the five year interval from 1915 to 1920. One of the large lamp manufacturers estimates that of the total in 1920 about 215,000,000 or about 92 per cent were tungsten filament lamps and about 16,000,000 were carbon filament lamps. This marked increase in the sale of incandescent electric lamps may be taken in a measure to represent fairly the growing use of electric lighting throughout the United States and it is of considerable interest to note here that the tungsten filament type has now almost entirely superseded the older carbon filament lamp.

The popular idea that the use of arc lamps is decreasing does not seem entirely consistent with the fact that the sale of luminous arc lamps during 1920 indicated an increase of more than 50 per cent over that of 1919.

Lighting in the Industries. The past year has evidenced marked attention on the part of factory managers to the effects of good lighting upon plant production, to the reduction of accidents and to minimizing spoilage. In one large industry an extended study was made to determine whether materially higher intensities of illumination than were formerly used, are warranted on the basis of improved production. These tests have not demonstrated fully just where practical intensity limits should be set for given classes of work nor what relations exist between good lighting and production, but the opinion is quite prevalent that higher intensities promote better workmanship and hence present practise tends towards the design of lighting systems with more liberal intensity levels than formerly.

The relation of poor lighting to accidents has received careful attention. It has been stated that during the 19 months the United States was in the last war, 56,000 American soldiers were killed in Europe, whereas during the same period 236,000 men, women and children were accidentally killed in this country. Of the enormous number of industrial accidents it has been fairly well established that possibly from fifteen to twenty per cent may be chargeable either directly or indirectly to poor lighting. This conclusion has been an item of importance in the work of regulating factory lighting by the State Departments.

The effect of light colored walls and ceilings on the

illumination resulting from lighting systems is well known to lighting men but not always appreciated as fully as it should be by plant operators. One of the most helpful efforts looking to a better understanding of wall and ceiling colors and their effects on the resulting illumination, has been Bulletin Number 41 issued by the National Lamp Works of the General Electric Company and prepared by Mr. Earl A. Anderson. This excellent bulletin contains sample colors with the corresponding reflection factors and the method of working these reflection factors into the design of a lighting system is clearly indicated.

Lighting Demonstrations. One of the results of the increased interest in high intensities has been the efforts of the lamp manufacturers to educate the industries up to the apparent advantages of better illumination by using the so called demonstration method of illustrating modern practise and its effectiveness. More or less permanent demonstrations have been installed in ten of the larger cities of the country and several others are in various stages of construction. This activity has been fostered by the National Electric Light Association, with the cooperation of local institutions. Similar travelling demonstrations have been conducted by the lamp manufacturers in about one hundred and twelve other cities.

The Pennsylvania Department of Labor and Industry took advantage of the portable demonstrations presented in that state, to educate manufacturers and others in the application of the Industrial Lighting Code.

The demonstrations have also been utilized for the benefit of engineering students; for example, the Edison Lamp Works of General Electric Company recently conducted demonstrations at the University of Pennsyvlania and at Yale University. These demonstrations have doubtless been generally very successful in making an impression concerning the advantages of adequate illumination.

Miscellaneous Items. It has been stated that the foot-candle meter is now being used much more than formerly for the measurement of illumination by the layman through inexpensive means. Several thousands of these instruments have been sold during the past year or so, and the demand for them by the industries, factory inspectors and others, continues to the extent of several hundred per month. An interesting modification of the earlier instrument has been an increase in its range from an upper limit of 25 foot-candles to one of 40 foot-candles so as to make possible the measurement of higher intensities than formerly.

Highway lighting has received considerable attention and a double reflector unit has been developed so as to reduce the waste of light on either side of the roadway. Among the important installations of street lighting which have been completed and put into operation during the past year or so have been those at Los Angeles, Cal., and Saratoga, N. Y.

It is significant and of special interest to central station operators to know that during 1920 nearly 80 per cent of all incandescent electric lamps sold were used on circuits of 110, 115 or 120 volts, whereas in 1913, by contrast, less than 50 per cent of the incandescent lamps sold were used on circuits of these voltages.

C. E. CLEWELL, *Chairman.*

MARINE COMMITTEE

To the Board of Directors:

In presenting the Annual Report of the Marine Committee only the outstanding features of the Committee's work will be dealt with, the vast amount of detail work involved should not be lost sight of however as it was only through the untiring efforts of the various sub-committees that such splendid progress was made.

On referring to the report of the Marine Committee for the season of 1919-1920, the following items are noted; these items represent subjects to be carried over to the following year or new departures recommended for consideration:

1. Rules for the Recommended Practise for Installations on Ship Board.
2. Work of Historical Committee.
3. Fixtures, Fittings, etc. to meet requirements of new rules.
4. Terminal Facilities at Marine Piers.

Eight meetings of the Committee were held. The first meeting convened on September 30th and October 1st, 1920 at Schenectady, New York and was very well attended. The following sub-committees were appointed:

a. American Standards.
b. Applicances.
c. Editing.
d. Propulsion.
e. Auxiliaries.

The Historical Committee was carried over from the previous year.

The year's work of the above sub-committees may be summarized as follows:

The duty of the American Standards sub-committee consists of the taking up with the American Engineering Standards Committee, the question of having the Recommended Practise for Electrical Installations on Ship Board passed by that Committee as a standard for American Practise. This could not be accomplished however, until these rules and recommendations were placed in printed form and circulated.

The duties of the Appliance sub-committee were to formulate a set of Standards covering electrical appliances which would later be incorporated in the Recommended Practise for Electrical Installation on Ship Board. The following is a partial list of appliances intended to be covered by this work:

Conduits and Fittings.
Junction Boxes.
Deck and Bulkhead Stuffing Tubes.
Receptacles, Watertight and Non-Watertight.
Electric Heating Appliances.
Running Tell Tale Panel.
Gaskets and other Watertight Packing Materials.
Pull Boxes.
Fuses.
Plugs, Watertight and Non-Watertight.
Switches, Watertight and Non-Watertight.
Fans.
Telephones.
Bells, Buzzers and other Electrical Signaling Devices.

The Editing sub-committee this year completed the final editing of the Recommended Practise for Electrical Installations on Ship Board and has been retained to handle all comments and proposed changes in regard to these rules which, from time to time, may arise. These changes to be submitted to the main Committee periodically for its action, and if adopted to be made a permanent part of these rules.

The following is given as a resume of the year's work of the Propulsion sub-committee:

It was first decided that Electric Ship Propulsion had not as yet reached a stage of development and continued use that would justify an attempt to draw up a set of Marine Rules or Recommendations for Propulsion Machinery to the same extent as had already been done for other electrical work. With this in view, the work of the Propulsion sub-committee resolved itself into the following:

a. Preparation of papers for an engineering meeting in New York.

b. The drawing up of a set of Rules or Recommendations for the proper preservation and protection of electric propelling apparatus during the time of installation and after being placed in service.

c. The preparation of a history of electric ship propulsion for use of the Historical sub-committee.

In connection with the preparation of papers for an engineering meeting in New York as mentioned above, the following statement may be made:

A joint meeting of the Metropolitan Section of the American Society of Mechanical Engineering and the Marine Committee of the American Institute of Electrical Engineers was held at the Engineering Societies Building, New York, on January 28, 1921. The following papers by members of the Propulsion sub-committee were presented:

Turbine Reduction Gears vs. *Electric Propulsion for Ships*, by Eskil Berg, of the General Electric Company.

Electric Propulsion of Ships, by W. Thau, of the Westinghouse Electric & Manufacturing Company.

Electrical Terminal Facilities, by C. S. McDowell.

The meeting was very largely attended and the papers read contained much useful information.

Recommendations were made by the Propulsion sub-committee for the preservation and protection of propelling machinery during the time of installation and after the apparatus had been placed in service. These recommendations have been completed and preliminarily passed by the Committee but will be carried over until next year before final reading and publication. The historical side of the work of the Propulsion sub-committee received quite considerable attention by that Committee. An extensive list of references of articles which have appeared in publications from the earliest days of electrical installation until about the year of 1911 have been prepared and turned over to the Historical sub-committee.

It was the intention that the work of the sub-committee on Auxiliaries should go along with that of the sub-committee on Electric Propelling Machinery for Engine Room Auxiliaries only. The Deck Machinery and Terminal Handling Apparatus was to be handled exclusively by this Committee. It is contemplated making the Recommendations of this sub-committee, with regard to the above subjects, part of the Recommended Practise for Electric Installations on Ship Board.

A considerable amount of effort has been expended by the Historical sub-committee upon its work during the past year, but owing to the extent of the task and the vast amount of time rquired for other activities of the Committee, it was found impracticable to compile its data complete and in detail for publication at this time. It was the original intention of this subcommittee to complete its work up until the year of 1910 but it was later decided to bring the work as far up to date as possible and then have it supplemented from time to time as developments in the field justified. It will no doubt be possible to turn into the Institute, sometime during the coming year, the work which has already been done by this sub-committee.

From the above it will be noted that the Committee has taken upon itself a great volume of work which cannot be accomplished in one year and probably will extend over a period of several years but considerable work has already been done by this year's Committee as follows:

The final revision and passing of the Recommended Practise for Electrical Installation on Ship Board has been completed and published by the Institute. The writing of papers and reading of the same at the joint meeting of the Metropolitan Section of the American Society of Mechanical Engineering and the Marine Committee of the American Institute of Electrical Engineers in New York. The drawing up of recommended practise for the protection and preservation of propelling machinery, also the vast amount of data on the historical side of electric ship propulsion and electrical installations on ship board. A Joint Meeting has been arranged with the Naval Architects and the Marine Engineers in New York in November at which time two papers will be presented, one on electric propulsion and the other on electric ship auxiliaries.

In concluding this report, I feel that I would be

evading my duty as Chairman of the Committee if I did not congratulate every member of the Marine Committee for his interest, attendance at meetings and general attitude with regard to all subjects that have come up for discussion at the various meetings throughout the year. The Committee as a whole has worked conscientiously and consistently and I believe deserves great credit for the amount of work that it has accomplished.

It is this thought in particular that I would leave with the Marine Committee for the ensuing year, that good work can only be accomplished through good will, consistent application and real cooperation.

ARTHUR PARKER, *Chairman.*

ELECTROPHYSICS COMMITTEE

To the Board of Directors:

ADVANCES IN ELECTROPHYSICS 1920-1921

Progress in physics is, as a rule, gradual and it is generally dfficult to look back over a space of one year and definitely state what will prove to be the most important advances of that period.

The members of this Committee were canvassed regarding the advances during 1920 and 1921, and it was the general opinion that the most striking and what will prove to be the most far reaching work is that of Rutherford on the atomic nucleus. Rutherford has bombarded the atoms of some of the lighter elements with alpha particles and has apparently succeeded in disintegrating them. Nitrogen was one of the elements thus desintegrated. Hydrogen was apparently found in some of the disintegrated atoms.

Work and speculation on the arrangement of the electrons in atoms and molecules seems to be leading to something, and it is hoped that the results will be of great importance.

Among other important work, that on isotopes might be mentioned. The above list is by no means complete but it touches on some of the work that at present stands out.

LECTURES AND PAPERS

It is regretted by this Committee that the electrophysics lecture was not given a place in the Midwinter Convention this year. This lecture in the past has been better attended than any other meeting. The following list of activities of the Institute in different parts of the country during the year is given as indication that electrophysics subjects are appreciated by our membership:

Philadelphia, October, 1920, *The Epoch Making Discoveries of the Years* 1819-1820, by Elihu Thompson. *Oersted's and Ampere's Discoveries,* by M. I. Pupin.

Pacific Coast Convention, July, 1920, *Centennary of the Discoveries of Oersted, Arago and Ampere,* by C. E. Magnusson.

New York, February, 1921, *Wave Transmission,* by M. I. Pupin.

The Electrophysics Committee during the past year has encouraged electrophysics lectures in the Sections. In this connection we were fortunate in assisting the Pittsfield and Schenectady Sections in securing Dr. R. A. Millikin to lecture on the *Twentieth Century's Contribution to our Knowledge of the Atom.* These lectures were very well attended and the discussions indicated a keen interest in the subject by the members.

The following technical electrophysics papers are to be presented at the Annual Convocation:

Electric Strength of Air under Continuous Potentials and as Influenced by Temperature by J. B. Whitehead and F. W. Lee.

Voltage and Current Harmonics Caused by Corona, by F. W. Peek, Jr.

F. W. PEEK, JR., *Chairman.*

HYDROELECTRIC DEVELOPMENT IN LATVIA

The Latvian Government is in possession of various plans for the installation of hydroelectric stations on the Duna (Dvina) River, which, for the most part, were developed by engineers of the Imperial Russian Government prior to the war. These plans constitute a somewhat complete scheme for utilizing the power of the Duna and also for developing the river, through a system of locks and short lateral canals, to make it navigable well into the interior of Russia proper and eventually, through a system of canals connecting with the Dnieper and other Russian rivers, to form an elaborate system of interior water transportation.

The plans foresee the eventual installation of five stations on the Duna River to a distance of approximately 65 miles upstream from Riga.

Of these five projects, the two most seriously discussed for the immediate future are the station at Dahlen, to be utilized for the city of Riga and its industries, and the station of Kokenhusen, to be utilized largely or entirely for railway electrification. Without thorough study it is impossible to say whether the market for electric current and the other relevant considerations would justify large expenditures in such undertakings; but at least the projects are such as to merit very serious consideration. A group of Germans, reported to be the builders of the Keil Canal, has already advanced a proposition to the Latvian government to undertake the installation of the station at Dahlen without special reference to the other four stations; a Belgian group has proposed that it be given the right of installing a station at Dahlen, with a concession for the other four stations to be erected at the company's discretion.—H. L. Groves, in *Commerce Reports.*

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SALT LAKE CITY CONVENTION

The combined Annual and Pacific Coast Convention held in Salt Lake City, June 21-24, will go down in Institute history as one of the most successful and enjoyable gatherings of its kind, far exceeding in interest the anticipations of the members and guests in attendance. This was the first time that the A. I. E. E. has staged an annual convention farther west than St. Louis, and the success of this innovation may well lend encouragement to those western members who hope to secure some of the future conventions for the far western states.

The registration of members and guests totaled 426, including 75 ladies. The attendance represented 29 states, Canada, Italy and Spain.

One of the pleasant features of the Convention was the attendance of an Italian delegation of engineers forming a commission on tour of the United States to inspect railway and industrial electrification. The commission was headed by Guido Semenza, E. E., consulting engineer for the Italian government, past president of the Assoziazione Electrotecnica Italiana, and Local Honorary Secretary of the A. I. E. E. for Italy; the other members were Marquis F. Cusani, business manager of the Italian-American Electric Company; Colonel Cesare Scarelli, C. E., head of railway transportation service, general staff, Italian army, and E. Boschetti, secretary; Professor G. C. Ponti, also a member of the commission, was obliged to return to Italy and was therefore unable to be present at the Convention.

The plan of confining the technical sessions to the mornings, which was inaugurated at the White Sulphur Springs Convention last year, has met with general approval and was carried out at the Salt Lake City Convention. These sessions were all well attended, and great interest was manifested in the discussions which related largely to high-voltage, long-distance transmission—a subject of particular importance at this time in view of the projected developments on the western coast.

The afternoons and evenings during the Convention were left open for inspection trips and numerous entertainment features which were provided in abundance by the Convention Committee. The provisions for entertainment and recreation reflected the well-known spirit of Western hospitality and left the busy visitors no time for ennui.

The Convention Committee under the able chairmanship of H. T. Plumb, of Salt Lake City, was indefatigable in its efforts to make the Convention thoroughly enjoyable for everyone in attendance. Each event on the Convention program was in charge of a special sub-committee whose efficient preparatory work resulted in a notable smoothness of operation in carrying out all of the Convention activities. Members of the Committee designated by special badges were constantly on hand to afford any services desired by those in attendance.

Every hospitality was offered the Convention visitors by the local clubs and other organizations. Club privileges were extended by the University Club, the Country Club, the Tennis Club, the Latter Day Saints Gymnasium, the Rotary Club, the Kiwanis Club and by all of the engineering societies in the city. Convention badges were the only credentials necessary to enter any of these clubs and feel at home.

In view of the many courtesies received, the Board of Directors at its meeting during the convention passed the following resolutions:

RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers, representing the members and guests in attendance at the Annual and Pacific Coast Convention at the Hotel Utah, Salt Lake City, Utah, June 21-24, 1921, hereby expresses its hearty appreciation of the excellent arrangements made by the Convention Committee for the comfort and entertainment of the members and guests of the Institute during the Convention.

RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses to

The Salt Lake City Commercial Club
The Salt Lake Country Club
The Latter Day Saints Church
The University Club
The Salt Lake Tennis Club
Utah Chapter, American Institute of Architects
Rocky Mountain Electrical Cooperative League
Electrical Contractors & Dealers Association
Los Angeles and Salt Lake Railroad
Bingham & Garfield Railway Company
Southern Pacific Railway Company
Western Pacific Railway Company
Utah Section, American Society of Civil Engineers
Utah Section, American Institute of Mining & Metallurgical Engineers
Utah Section, American Association of Engineers
Utah Copper Company
Salt Lake, Garfield & Western Railroad Company
Utah Power & Light Company
Utah Society of Engineers
Utah Section, American Society of Mechanical Engineers
Salt Lake Tribune
Salt Lake Telegram
The Deseret News
The New West Magazine
Consolidated Ticket Office
Oregon Short Line Railway Company
Chicago, Burlington & Quincy Railroad Company
Denver & Rio Grande Railway Company

its hearty appreciation of the many courtesies extended by them to the members and guests in attendance at the Annual Convention of the Institute, held in Salt Lake City, June 21-24, 1921.

TUESDAY, JUNE 21

Opening Session. The Convention was called to order at 10 o'clock by Mr. Plumb, chairman of the Convention Committee, who introduced Dean Merrill, of the University of Utah, and chairman of the Utah Section. Dean Merrill welcomed the engineers most heartily and hoped that their time would be so profitably and pleasantly spent and the Convention would be so successful that they would want to come again. Alluding to the electrical developments at Salt Lake City,

Dean Merrill said: "In many of the homes of this city the food is cooked electrically, our homes, our farms, our mines, and mills and interurban railways are all equipped electrically, and the time will soon come within a few years when hundreds of thousands of acres now barren waste near this city will be converted into smiling fields as a result of water pumped by electricity. We believe in electricity—we believe in the electrical life, and so again we welcome you with the spirit of fellowship as apostles of this faith."

Mr. Plumb then turned the meeting over to President Berresford who delivered his presidential address on *Personal Observations in the Industry*. The address is printed in full in the July JOURNAL. Following his address, President Berresford welcomed the members of the Italian Commission to the Convention and called upon its chairman, Mr. Guido Semenza, for some brief remarks. Mr. Semenza thanked the president for calling attention to the presence of the Commission, and said in part: "Professor Ponti, another member of the Commission, has been with us until a few days ago. He was obliged to go back to Italy, and as he is also a member of your Institute he asked me to express his regrets at not being able to be present at this meeting. As to myself, I am an old member of this Institute but it is the first time I have had an opportunity to assist. Italy, after all the havoc of the war and the after effects of the war, is picking up, and we are doing some active and efficient work. One of the examples of the new life of the country is the sending over of this Commission to get into contact with your people and your works and to learn of all that is new in your great country. As I have had the honor of being the president of the Italian Electrotechnical Association, I am glad to bring you here the expression of the feeling of brotherhood, and they are sincere and we feel admiration for the splendid work you are doing."

The next order of business was the presentation of the annual reports of the Technical Committees. C. Edward Magnusson, chairman of the Educational Committee, H. P. Liversidge, chairman of the Power Stations Committee, E. B. Meyer, chairman of the Transmission and Distribution Committee and H. L. Hibbard, of the Marine Committee, presented the reports of their respective committees in abstract. The other committee reports were presented by title only.

President Berresford then invited Prof. Slichter, chairman of the Meetings and Papers Committee, to conduct the meeting and the first two papers of the program were presented. The paper on *Hydroelectric Developments at Niagara Falls*, by J. L. Harper and J. A. Johnson, was abstracted by Mr. Johnson, and the one entitled *Advances in the Art of Waterwheel Designs and Settings*, by W. M. White, was presented by the author.

The two papers were then thrown open for discussion, in which the following members participated: E. R. Pragst, W. Baum, W. M. Moody, W. J. Foster, E. M. Breed, and J. A. Johnson, with closures by the authors. The meeting then adjourned.

Sections Committee Luncheons. At 12:30 o'clock a luncheon was held under the auspices of the Sections Committee and was attended by the official delegates of the Sections, past chairmen of Sections, officers of the Institute and officers elect. The luncheon opened the first conference of Section Delegates for which a long program of topics for discussion ahd been prepared. A summary of this meeting is printed elsewhere in this issue.

Ladies Luncheon. A luncheon was tendered the ladies attending the Convention, at the University Club. There were 45 ladies present. The party was escorted from the Hotel Utah to the club house at 12:30 by the ladies Committee. The luncheon was followed by brief remarks from several of the ladies.

Organ Recital. An organ recital largely attended, was given in the Mormon Tabernacle at 3:00 p. m. This organ is a remarkable instrument, originally constructed by Utah artisans, mostly from native materials. Various additions and improvements have been made from time to time, until it now contains between 7000 and 8000 pipes divided into seven sections. Its mechanism is entirely electrically operated. A number of musical selections was rendered showing the wonderful possibilities of this mammoth instrument, after which President Grant, of the Mormon church, gave an interesting account of the experiences and work of the Mormon pioneers. The party was then escorted to the numerous points of interest in the Temple Block which contains the Tabernacle, the Temple and other historical buildings and monuments of the Mormon Church.

Wausatch Drive. At 7:30 p. m. the party was taken for an automobile drive over a scenic route through one of the many canyons radiating out from the city, and on the return passed along Capitol hill, where the State Capitol stands in prominent view. This two-hour ride in the cool of the evening, over excellent roads, through the wild mountain scenery of the Rockies, was greatly enjoyed by all.

Reception and Dance. The closing event of a busy day was the reception held in the Utah hotel ballroom at 9:30 p. m. This was an informal function, and after the presentations to the president and other officers of the Institute and ladies in the reception line were completed, dancing followed during the rest of the evening.

WEDNESDAY, JUNE 22

Technical Session. The session was opened by President Berresford who called the meeting to order, and asked Chairman Meyer, of the Transmission and Distribution Committee, under whose auspices the session was held, to take the chair and conduct the meeting.

The first paper of the morning was *Long-Distance Transmission of Electric Energy*, by L. E. Imlay, which in the author's absence was abstracted by the chairman. This was followed by a paper on *Voltage and Power Factor Control of 66,000-Volt Transmission Lines Connecting Two Generating Stations*, by Raymond Bailey, which was presented by H. P. Liversidge. A paper on *Voltage Regulation and Insulation for Large Power Long-Distance Transmission Systems*, by F. G. Baum, was abstracted by the author, after which a paper on *Some Transmission Line Tests*, by W. W. Lewis, was presented by the author. In the absence of the author Chairman Meyer presented a paper entitled *Notes on the Operation of Large Interconnected Systems*, by L. L. Elden, and the last paper of the morning, *Modern Production of Suspension Insulators*, by E. H. Fritz and G. I. Gilchrest, was presented by Mr. Gilchrest.

The discussion which followed was opened by W. I. Slichter and was participated in by L. P. Ferris, Buckner Speed, F. W. Peek, Jr., M. E. Skinner, C. L. Fortescue, Harris J. Ryan and F. G. Baum, and written discussion by J. T. Barron.

Bingham Excursion. At 12:30 on Wednesday the Convention party boarded a special train for the town of Bingham where the Utah Copper Company's mine is located. A substantial box luncheon was served on the train shortly after starting, and the trip to the mines occupied about two hours, passing through Garfield, which contains a large smelter, Arthur, where a very large copper concentrating plant is located, Magna, where the largest concentrating plant in the world is situated, and Bacchus, where there is a very large plant for the manufacture of high explosives and black powder. The train climbed the mountains by a devious route, along ledges, over bridges and through tunnels, many places affording remarkable views of mountain scenery.

Arriving at Bingham about 2:30, the train was taken up over the mine to the "E Level" where the party disembarked. Here was afforded a unique view of the open copper mine of the Utah Copper Co., the largest open copper mine in the world. It consists of a series of levels some 25 or 30 in number, extending to the extreme summit of the mountain. Each with its track on which the steam shovels and ore trains operate. In

times of maximum production the average daily output is 34 000 tons of ore and 32,000 tons of stripping, and 22 steam shovels, 56 locomotives and 1000 ore cars have been kept in operation day and night.

The town of Bingham, as viewed from the train, presents an unusual appearance. Situated at the bottom of a deep canyon, it is several miles long with only width enough for a single street.

On the return trip, stops were made at Arthur to inspect the concentrating plant, and Garfield, where the party visited the smelter works and Cottrell precipitation plant.

Music Recital. A piano, harp and vocal recital was given in the Hotel Utah ballroom at 8:30 p. m. at which several piano solos were rendered by Mr. Jacob A. Kahn, vocal solos by Mrs. Lloyd Weeter, and harp solos by Mrs. Marsh Boothby. The performance was much appreciated by a capacity audience which called for numerous encores.

Sections Committee Conference. The conference which commenced at the Delegates Luncheon was continued at the open conference held at 9:30 p. m. The program of Section and Institute affairs proposed for discussion was a long one and occupied the attention of the meeting until after 1:00 a. m. Further details of this meeting will be found elsewhere in this issue of the JOURNAL.

THURSDAY JUNE 23

Technical Session. After being called to order by President Berresford, the conduct of the meeting was turned over to Mr. F. G. Baum who announced that the papers for the morning would be read, after which the papers for both Wednesday and Thursday would be discussed together. The papers for the session were then presented as follows: *Voltage and Current Harmonics Caused by Corona*, by F. W. Peek, Jr., read by the author; *A Solution of the Porcelain Insulator Problem*, by E. E. F. Creighton and F. L. Hunt, read by Mr. Creighton; *Transformer for Interconnecting High-Voltage Systems or for Feeding Synchronous Condensers from a Tertiary Winding* by J. F. Peters and M. E. Skinner, abstracted by Mr. Skinner, and *Electric Strength of Air Under Continuous Potentials and as Influenced by Temperature*, by J. B. Whitehead and F. W. Lee, abstracted by Dr. Whitehead.

The discussion of the two days' papers which followed resolved itself into a rather general discussion of long-distance power transmission, with the following members participating: A. O. Austin, K. A. Hawley, G. I. Gilchrest, E. E. F. Creighton, H. J. Ryan, W. W. Lewis, F. W. Peek, Jr., A. W. Copley, L. H. Burnham, R. D. Evans, M. E. Skinner, J. P. Jollyman, J. A. Johnson, S. Barfoed, C. L. Fortescue, A. H. Lawton, L. P. Ferris, J. B. Whitehead, H. R. Summerhayes.

Ladies' Ogden Excursion. A party of 65 ladies left the convention headquarters at 10:00 o'clock Thursday morning on a special auto excursion to Ogden canyon. The ride covered a distance of 100 miles along the foothills of the Wasatch mountains. Luncheon was served at the Hermitage. The ride occupied nearly the entire day, the party returning at 6:00 p. m.

Board of Directors Meeting. At 12:30 the members of the Board of Directors present at the Convention assembled at luncheon after which a meeting was held. A notice of this meeting appears elsewhere in this issue of the JOURNAL.

Terminal Substation Inspection. A large party of the visiting engineers was taken by automobiles at 3:00 p. m. to the Terminal Substation of the Utah Power and Light Co., which is located about five miles outside the city. This company operates a hydroelectric development which includes 30 water powers and one steam reserve, and covers an area 375 miles long by 75 miles wide. The Terminal Substation is the terminus of three 130-kv. transmission lines aggregating 402 miles in length, the current from which is stepped down to 44,000 and 6600 volts in outdoor apparatus. The substation contains two 7500 kv-a., 6600-volt synchronous condensers.

The party divided into small groups each in charge of a guide who explained the construction and operation of the plant in detail, and afforded every opportunity for inspection and study of the system.

Lecture. Thursday evening was devoted to a lecture on the "Natural Parks of Utah" by Dr. Broaddus, in the Hotel Utah ballroom. The lecture was illustrated with beautifully colored lantern slides.

FRIDAY, JUNE 24

Technical Session. The last technical session of the Convention was called to order by President Berresford who called for the paper *Little Things from Little Places* by Guido Semenza. Mr. Semenza's paper gave a very interesting account of the electrical developments in Italy and the expansion of the electrical industry which has occurred since the war, due to changed conditions. He described some interesting contrasts in Italian and American practise many of which he ascribed to the larger number of individual manufacturers in Europe and the correspondingly larger number of variations in the design of electrical apparatus.

President Berresford then turned the meeting over to Mr. F. W. Peek, Jr., who called upon the authors to summarize their papers. The papers on *Synchronous Motors for Ship Propulsion*, by E. S. Henningsen, and *Magnetic Properties of Compressed Powdered Iron*, by Buckner Speed and G. W. Elmen, were presented respectively by Mr. Henningsen and Mr. Speed. In the absence of the author, the paper on *Heat Losses in Conductors in A-C. Machines* by W. V. Lyon, was presented by title only.

The joint discussion which followed was by the following contributors: H. W. Taylor, W. J. Foster, F. G. Baum, W. Fondiller, H. L. Hibbard, Guido Semenza, C. A. Copley, W. E. Thau, P. P. Ashworth, S. P. Grace, A. M. MacCutcheon, E. S. Henningsen and Buckner Speed.

President Berresford then declared the meeting adjourned.

Ladies' Auto Ride. An auto. ride to Parley's Canyon was enjoyed by 40 ladies, leaving the Hotel Utah at 11:00 a. m. A stop was made at the Country Club where luncheon was served.

Baseball Game. The baseball game which was scheduled between the Eastern and the Western members was called at 2:00 p. m. on the Municipal Baseball grounds of Salt Lake City. The teams were made up as follows:

East		West	
Kelley—Captain	cf	Davoud—Captain	cf
MacCutcheon	2b	Pratt	lf
Harms	3b	Evans	ss
Henningsen	lf	Stayner	3b
Dennison	1b	Ashworth	1b
Schifer	p	Merrill	rf
Johnson	ss	MacDonald	2b
Ward	c	Perrin	c
Watkins	rf	Gardner	p

Score: East 9
West 23
Umpire: Mr. Stevens
Scorekeeper: Mrs. Ashworth

Golf. On account of the large number of other conflicting diversions it seemed inadvisable to attempt to tie up the members for a number of consecutive afternoons at golf. Consequently the competition for these trophies instead of being held at match play, as has been customary in the past, was held at handicap medal play, the contest being decided in one round. Under the conditions this was considered preferable since interesting trips were scheduled for each afternoon and it was found that comparatively few members cared to give up these trips in preference to golf.

The John B. Fisken trophy, which is competed for in the Pacific Coast Sections was won by Charles P. Osborne of Port-

land, Oregon. The Mershon trophy was won by Howard Maxwell, Schenectady, N. Y.

Saltair Trip. The excursion to Saltair, the popular bathing and amusement resort of Salt Lake City, was the last event of the Convention and was largely attended. Many of the party enjoyed the novelty of bathing in the water of Salt Lake which is so dense that it is hardly possible to sink in it. At 7:00 o'clock dinner was served in the Ship Cafe after which Chairman Plumb called upon several speakers for some brief remarks. In closing, President Berresford said that he had attended every A. I. E. E. convention, except one, for 15 years so he could be considered an expert on conventions. The major part of a successful convention is an intelligently and well selected program—*well carried out.* The Salt Lake City Convention was different from all others held, in that it has fulfilled these conditions to the letter, exceeding expectations in every detail. He expressed his hearty thanks for the splendid achievement of the Utah Section.

Many of the convention party enjoyed various after-convention trips to the Pacific Coast, Zion Canyon, Grand Canyon, Yellowstone Park, etc.

SECTION DELEGATES' CONFERENCES

The Constitution of the Institute provides that each Section may be represented at the Annual Convention by "an official delegate" (usually the Chairman of the Section). The by-laws provide that the duties of these delegates shall be "to attend such meetings of the Sections Committee as may be held during the Convention, to exchange views and experiences in connection with Section activities and management, and to make recommendations of an advisory nature upon such matters to the Board of Directors." Delegates' deliberations at the Annual Convention therefore take the form of Sections Committee meetings.

A program committee for meetings of the Sections Committee was appointed, by Chairman John B. Fisken, some months prior to the Convention, consisting of Messrs. E. H. Martindale, Chairman, John C. Parker and Robert Sibley. This committee communicated with all Sections of the Institute inviting suggestions of topics for discussion, in response to which twenty-one topics were listed on the program for discussion at two meetings which were held, at luncheon on Tuesday, June 21 and during the evening of Wednesday June 22.

Delegates Present

The following is a complete list of the official delegates present, forty Sections being represented,—the largest representation at any meeting of delegates since the present pract se was established.

Section	Delegate
Akron	A. P. Regal
Atlanta	A. M. Schoen
Baltimore	John B. Whitehead
Boston	W. I. Middleton
Chicago	M. M. Fowler
Cleveland	A. M. MacCutcheon
Connecticut	L. W. W. Morrow
Denver	D. C. McClure
Detroit-Ann Arbor	C. Kittredge
Erie	M. C. Goodspeed
Fort Wayne	J. J. Kline
Indianapolis-Lafayette	J. Lloyd Wayne, 3rd.
Ithaca	J. G. Pertsch, Jr.
Kansas City	Geo. C. Shaad
Lehigh Valley	J. L. Beaver
Los Angeles	R. W. Sorensen
Lynn	A. K. Warren
Madison	Edward Bennett
Milwaukee	H. W. Cheney
Minnesota	J. D. Marshall
New York	W. I. Slichter
Omaha	P. H. Patton
Philadelphia	H. P. Liversidge
Pittsburgh	B. C. Dennison
Pittsfield	F. W. Peek, Jr.
Portland	W. C. Heston
Providence	F. N. Tompkins
Rochester	H. J. Schiefer, Jr.
St. Louis	J. L. Woodress
San Francisco	J. P. Jollyman
Schenectady	H. R. Summerhayes
Seattle	J. P. Growdon
Spokane	H. V. Carpenter
Syracuse	Rich D. Whitney
Toronto	F. R. Ewart
Urbana	E. A. Reid
Utah	J. F. Merrill
Vancouver	C. N. Beebe
Washington	L. D. Bliss
Worcester	Francis J. Adams

The officers and officers-elect present were: President A. W. Berresford, Milwaukee; Vice-Presidents C. E. Magnusson, Seattle, and E. H. Martindale, Cleveland; Manager, W. I. Slichter, New York; Secretary, F. L. Hutchinson, New York; Vice-Presidents elect, John C. Parker, Ann Arbor and F. R. Ewart of Toronto. Others who attended the luncheon-meeting on Tuesday included John B. Fisken, Chairman of the Sections Committee, and the following officers and past officers of Sections: A. H. Babcock, R. B. Bonney, J. C. Clark, C. R. Higson J. L. Hamilton, W. P. L'Hommedieu, A. S. Peters, H. T. Plumb and B. C. J. Wheatlake.

Chairman Fisken of the Sections Committee called the first meeting to order and made a brief statement outlining the purpose of the conferences, which was to afford an opportunity for the representatives of the Sections to confer together and with the officers regarding Institute activities, particularly those relating to Sections.

President Berresford made a brief address emphasizing the value and importance of the annual conferences of the delegates.

The program was then taken up, the first topic being, "Ways and Means of Stimulating Attendance and Interest in Section Meetings." A long discussion followed, lasting until the close of the session at 2:45 p. m., during which many valuable suggestions were made.

On Wednesday evening, June 23d a second meeting was held at 8:30 o'clock, during which the remainder of the program was discussed by the members referred to above and many others, the meeting being open to all interested.

A resolution was adopted recommending to the Board of Directors that a joint committee of representatives of the Institute and other national engineering societies having llocal sections be organized to study the conditions in various locatities and recommend some uniform method of cooperation of sec ions of these societies and other local technical organizations ofhigh standing within any one locality.

After a long discussion regarding the policy to be followed regarding the Institute's publications it was the consensus of opinion that both the monthly JOURNAL and the annual TRANSACTIONS should be continued. but that the duplication of expense by printing the same papers in both publications should be eliminated as far as possible by including in the TRANSACTIONS only material of permanent value and that matter of ephemeral value should be published only in the JOURNAL; also that highly theoretical and mathematical papers be printed by abstract only in the JOURNAL, but in full in the TRANSACTIONS, provision being made that any member may obtain a complete pamphlet copy without charge upon application to Institute headquarters, and that notice to this effect be published in the JOURNAL with the abstract.

Motions were adopted recommending the plan outlined above to the Board of Directors; also a motion to the effect that the TRANSACTIONS be furnished hereafter to Fellows and Members without charge over the annual dues but only upon application each year and upon payment of postage or other forwarding charge; that TRANSACTIONS be furnished to Associates only upon payment of a charge, not exceeding five dollars per year.

Many other recommendations were made to the Board of Directors and later in the Summer an abstract of the entire discussion at both meetings of the delegates will be printed in pamphlet form and forwarded to all delegates and officers of Sections, also, upon application to Institute headquarters, to any other member who is interested. Both conferences were exceedingly interesting and profitable to all in attendance, as indicated by the fact that the second session did not adjourn until 1:20 a. m. Thursday, June 23.

DIRECTORS MEETING

The Board of Directors met at a luncheon meeting on Thursday, June 23, 1921. Present: President A. W. Berresford; Vice-Presidents C. E. Magnusson and E. H. Martindale; Manager W. I. Slichter; Secretary F. L. Hutchinson; Vice-Presidents-Elect John C. Parker and F. R. Ewart. In the absence of a quorum various matters were acted upon tentatively, all to be submitted to the Executive Committee for ratification later.

AMERICAN ENGINEERS HONORED ABROAD

John Fritz Medal Presentation Ceremonies

The American delegation of engineers which recently visited London and Paris to present the John Fritz Medal to Sir Robert Hadfield and M. Eugene Schneider, as announced in previous issues of the JOURNAL, was received abroad with the highest honors, and the courtesies extended by large numbers of distinguished members of the profession in England and France marked the visit as one of international importance.

The delegation, representing the four societies of Civil, Mining, Mechanical and Electrical Engineers, consisted of: Mr. Ambrose Swasey, Chairmen; Mr. Charles T. Main; Mr. R. A. Cummings; Mr. J. R. Freeman; Dr. Ira N. Hollis; Mr. Jesse M. Smith; Colonel A. S. Dwight; Mr. C. F. Rand; Mr. William Kelly; Dr. F. B. Jewett; Dr. A. E. Kennelly; and Major-General George O. Squier.

The reception to the American delegation in London at the Institution of Civil Engineers was attended by an unprecedented representation of British Engineers. Almost all of those occupying official positions in any of the Great British societies were present, as well as many other distinguished members; and there were also present: Lord Brice; Sir Robert Horn; and the American Ambassador, Mr. George Harvey.

A warm welcome to the visitors was offered by Mr. John A. Brodie, President of the Institution of Civil Engineers, which was responded to by Dr. Hollis, who, in conclusion, presented Mr. Brodie an illuminated address of greeting from the Engineers of the United States to the Engineers of Great Britain, signed by the Presidents of the four American Societies. The presentation was acknowledged by Dr. Unwin, after which Lord Brice joined in the welcome to the American Engineers.

The award of the John Fritz Medal to Sir Robert Hadfield was made by Mr. Ambrose Swasey who mentioned that Lord Kelvin and Sir William White had been previous British recipients, and expressed gratification at the selection of another British scientist for this distinction.

Sir Robert Hadfield had prepared an address of thanks, printed in book form, and made only a brief verbal response on receipt of the medal. He stated that he accepted it as not only for himself personally, but as an expression of the engineers in the United States of the high regard of the work of the British engineers in the war.

During this visit Dr. Swasey was presented with an honorary membership in the Institution of Mechanical Engineers, and Mr. Rand was made an honorary member of the Iron and Steel Institute. Mr. Swasey and Mr. Rand were also made honorary members of the Athenaeum Club of London. The delegation was further entertained at several brilliant receptions and dinners given in its honor.

A wonderful reception was also accorded the delegation in Paris, where it went to present the medal to M. Eugene Schneider. The presentation took place at the headquarters of the Society of Civil Engineers, under the presidency of M. le Trocquer, Minister of Public Works. The presentation ceremonies were opened by M. Chagnaud, with a speech recalling the debt which France owed to her sister Republic. Dr. Hollis followed with a speech in which he expressed his admiration of France's effort, both in war and in peace. The medal was then presented by Mr. Swasey to M. Schneider, who said that he accepted the medal as an honor conferred on French engineers as a whole through him. At the conclusion of the ceremonies, M. Chagnaud announced that Mr. Swasey had been made an officer of the Legion of Honor, and pinned an insignia of the order on Mr. Swasey's breast.

A morning reception was tendered the delegation by M. Gustave Eiffel on the top story of the Eiffel Tower. At noon a luncheon was served on the second floor of the Tower, the guests including the members of the delegation, and a large number of leading French engineers and scientists. An address of welcome was made by M. Chagnaud and was responded to by Dr. Kennelly and M. Schneider.

The keynote of most of the speeches in both England and France was the international character of engineering, and the importance of developing intimate relations between the members of the professions of the different countries, leading to a better understanding between the nations.

ROYAL SOCIETY OF ARTS AWARD

Albert Medal to Dr. J. A. Fleming of London

Dr. John Ambrose Fleming, F. R. S., has been awarded the Albert Gold Medal of the Royal Society of Arts (Great Britain) for 1921, in recognition of his many valuable contributions to electrical science and its applications, and especially of his original invention of the thermionic valve, now so largely employed in wireless telegraphy and for other purposes.

Dr. Fleming, who has held the Chair of Electrical Engineering in University College of the University of London for 36 years, has been closely associated for the last 42 years with the practical and scientific developments of electricity in Great Britain. In 1879 he was scientific adviser of the Edison Telephone Company, formed to begin telephone exchange working in London, and for some years thereafter held similar scientific positions in connection with other companies. He assisted also the early progress of electric lighting in London, both in an advisory and a working capacity, one of his first accomplishments along this line being to carry out the electric lighting of one of the first ships to be so lit in the royal navy (an Indian troopship) when the illuminant was introduced in 1882.

After the initiation of practical wireless telegraphy by Senator Marconi in 1899, Dr. Fleming aided in its development, and directed some of the early constructional work in connection with the first long-distance wireless station at Poldhu. In 1904 he invented the first form of the thermionic valve or detector, which in its later improved forms due to subsequent inventors has been of great importance in wireless telegraphy and telephony.

The author of numerous valuable papers contributed to scientific societies, Dr. Fleming has also written various textbooks or treatises on electrical subjects which have had worldwide circulation. His most recent book is entitled "Fifty Years of Electricity, the Memories of an Electrical Engineer," in which he has described the chief notable achievements of Electrotechnics in the last half century, with many of which he has been intimately connected. He is a well-known lecturer in London, addressing working class audiences as well as uni-

versity and college, and frequently lecturing before scientific societies.

Besides the Albert Medal award of 1921, Dr. Fleming has received other recognition of his achievements. In 1892 he was given the Fellowship of the Royal Society; in 1910 he was awarded the Hughes Gold Medal by the Royal Society; twice did the Institution of Electrical Engineers award to him the Institution Premium, in 1903 and 1912; the Society of Engineers has awarded to him The Bermays Prize; and from the Royal Society of Arts he has received a Silver Medal.

The Albert Gold Medal was instituted in 1862 as a memorial of the Prince Consort, and is awarded annually for "Distinguished merit in promoting arts, manufactures, and commerce." Among its previous recipients are numbered Mr. Edison, who received the medal in 1892, and Alexander Graham Bell, to whom the award was made in 1902. It is the highest distinction given by the Royal Society of Arts.

PAGEANT OF PROGRESS EXPOSITION

Chicago, July 30-August 14

The Pageant of Progress Exposition, to be held in Chicago on the $5,000,000 municipal pier, July 30 to August 14, will be one of the notable expositions of today. Inaugurated to encourage trade and industry, the exposition will represent practically every phase of American industrial and commercial activity. There will be over 3½ miles of exhibits, divided into sections, and representing groups of industries. Among the features of the electrical exhibit will be wireless concerts, played nightly at Pittsburgh and received at the end of the pier, being relayed so as to be heard at 200 places at one time. An amusing exhibition will be electrically operated animals, "ranging from dragons to an electrical Fido."

In addition to the exhibits there will be many features to attract visitors, such as naval maneuvers, pageantry, street parades, races between some of the fastest motor boats in the world, and various athletic sports.

William Hale Thompson, mayor of Chicago, is president of the exposition, and the city's leading organizations are giving their support to make it a big success.

NATIONAL EXPOSITION OF CHEMICAL INDUSTRIES

New York, September 12-17

The Seventh National Exposition of Chemical Industries will be held at the Eighth Coast Artillery Armory, New York City, during the week of September 12th. This year's exposition, like previous ones, will be a most valuable and interesting display, representing every branch of the chemical industry, and introducing to the public many new and important developments in chemistry. Growing in importance each year, the National Exposition of Chemical Industries has come to be of much scientific and educational value, as well as an interesting industrial display. This year there will be delegations at the exposition from England, France and Canada. The progress of chemical research in the United States since the war started has been remarkable, and the exposit on to take place in September promises to be the greatest in the history of this country's chemical industry.

MANAGEMENT ENGINEERING

Management Engineering is the title of a new monthly magazine which made its initial appearance in July. It is edited by L. P. Alford assisted by Edward W. Tree, and published by the Ronald Press Co. of New York. The object of the new magazine, as described in its prospectus, is to help operating executives to attack managerial problems with definite plans and to employ to best advantage the machinery and labor at their disposal. The first number of the magazine, containing several articles by well-known engineers and executives, gives promise of fulfilling its mission very effectively. A convenient feature of the new pub ication is the printing at the head of each article the classification and index number corresponding to the system used in the Engineering Societies Library. Mr. Alford, both as an editor and an engineering executive, needs no introduction to an engineering audience; and Mr. Tree brings to the magazine his experience as associate editor of *Mechanical Engineering*. The new journal starts out well, and we wish it every success.

FRANCIS BAYARD CROCKER

Francis Bayard Crocker, past-president of the Institute, and one of the leading electrical engineers of the world, died on July 9, 1921, at his home in New York City.

Dr. Crocker was born in New York, July 4, 1861. From his childhood days he was interested in electricity, then barely known as a science, and as a boy he built successful telegraph and telephone lines. He attended school in New York, and was graduated from the School of Mines, Columbia College, in 1882.

The year following his graduation he formed with Charles G. Curtis the firm of Curtis & Crocker, and for five years they were engaged in patent and expert work almost entirely electrical. During that time they invented and patented the C & C electric motor, and established the company of that name. When Mr. Curtis had to withdraw from business on account of illness, Mr. Crocker joined with Schuyler S. Wheeler in the firm of Crocker & Wheeler, Electrical Engineers. This was the forerunner of the Crocker-Wheeler Company, now one of the prominent electrical manufacturing concerns of the country. Dr. Crocker was a director of this company at the time of his death.

Interested in the electrical industry, Prof. Crocker at the same time gave his energy and intellect to the development of the science. He founded the School of Electrical Engineering at Columbia University, and remained head of it for twenty years. As a teacher he endeared himself to thousands of students.

During the war Dr. Crocker was an advisor for the members of the Naval Consulting Board, refusing to become a member, however, on account of poor health. His researches in aeronautics were of great importance, and many of his discoveries are now in practical application. With Peter Cooper Hewitt he developed in 1917 the first helicopter in this country which was able to fly. Successful inventors frequently sought his advice and information, for his scientific knowledge was exceptional, extending into many fields besides those of electricity and aeronautics.

As Chairman of the first Standardization Committee of the A. I. E. E., Dr. Crocker gave his painstaking work to the standardization of electrical equipment. To obtain a complete standardization of electrical equipment throughout the world was one of the objects of his life, and in connection with this work he was one of the two American delegates to the International Electrotechnical Commission meeting in London in 1906. Lord Kelvin on this occasion said of him, "He is one of the world's two greatest electrical engineers."

Besides being Chairman of the Standardization Committee Dr. Crocker was active in the Institute in other capacities. He served as vice-president, president and manager.

Dr. Crocker was a former president of the Electric Power Club, and of the New York Electrical Society, and was a past secretary of the International Electrotechnical Commission.

With Dr. Crocker's death, engineers feel the loss of an able thinker and a great scientist, whose contributions to the world's progress will remain a lasting monument to his memory.

PERSONAL MENTION

SAMUEL ROBINSON, Commander, U. S. Navy, is now in the Bureau of Engineering, Navy Department, Washington, D. C.

J. V. HUNTER, western editor of *American Machinist*, in Chicago, has left that work to become editor of *Motor Service*, Chicago.

R. J. ANDRUS has left the Central Power Company, Grand Island, Neb., to locate with the Middle West Utilities Company of Chicago.

C. S. MCDOWELL, Commander, U .S. Navy, received the honorary degree of Doctor of Science from the University of Wisconsin, on June 22, 1921.

H. H. BRADLEY, of the International General Electric Company, has left the Schenectady office to become special representative for the company in San Juan, Porto Rico.

H. E. EISENMENGER is located with the New York Edison Company, New York City, He was with the Techno Service Corporation, New York, for the past year.

GORDON W. FALLIS has left his position as electrician with the Puget Sound Power & Light Co., Dieringer, Wash., to enter the Lighting Depratment of the City of Seattle.

M. M. KOCH, formerly field engineer with Henry L. Doherty, New York City, has gone to Denver, Col., where he will be with the Denver Gas & Electric Light Company.

F. L. HUTCHINSON, Secretary of the A. I. E. E., was married at San Diego, Cal., on June 27th, to Mrs. Grace Lawrence Duryee of San Diego, formerly of Elizabeth, N. J.

R. M. CRITCHFIELD, formerly assistant chief engineer of the Dyneto Electric Corporation, Syracuse, N. Y., is now associated with the Remy Electric Company, Anderson, Ind.

LEROY C. WILLIAMS has left his work as sales engineer with the Westinghouse Electric & Mfg. Co., San Francisco, and is engineer with the Alberhill Coal and Clay Co., Los Angeles.

ARCH ROBISON, formerly construction superintendent with the J. G. White Engineering Corporation, Marcus Hook, Pa., is with the Southern Utilities Company, West Palm Beach, Fla.

VICTOR T. MAVITY is now electrical engineer with the Chaparra Sugar Co., Chaparra, Oriente, Cuba. He was previously with the Colonial Sugar Co., of Central Constancia, Cienfuegos, Cuba.

R. A. GLADWELL, who has been associated with the General Electric Company since 1919, has left for Rugby, England, where he will be located with the British Thomson-Houston Company.

W. E. SANBORN is now a member of Cain & Sanborn, Inc., East Orange, N. J. Mr. Sanborn is secretary and treasurer of the firm. He had been located with Thomas A. Edison, Inc. Orange, N. J.

W. S. MURRAY and HENRY FLOOD, JR., who were engaged on the Superpower Survey of the U. S. Geological Survey, have opened an engineering office in the Grand Central Terminal, New York City.

GLEN D. BAGLEY, until recently with the Electro Metallurgical Co., Niagara Falls, N. Y., has become associated with the Union Carbide and Carbon Research Laboratories, Inc., Long Island City, N. Y.

HAROLD L. BALLARD, who has been instructor in Electrical Engineering at the University of Michigan, is at present associated with the Michigan State Telephone Company, Detroit, as transmission inspector.

E. T. STREET, until recently mechanical superintendent of the Standard Paint Co., Joliet Ill., has accepted the same position with the Rubenoid Co., of Bound Brook, N. J., and Joliet, Ill. He is located at Bound Brook.

ARTHUR E. ULRICH has been appointed Far Eastern representative of Joseph T. Ryerson & Son of Chicago, and will be located in the Tokyo office. He was formerly New York representative of the export department of the company.

FERMON L. NEWTON is at present manager of the Meter & Service Department of the Empire District Electric Co. of Oklahoma, at Picher, Okla. Until recently he was employed with the Wichita Falls Electric Co., Wichita, Falls, Tex.

J. D. SPARKS has been appointed representative in Utah, Idaho and Montana, of Landers, Frary & Clark, New Britain, Conn. Mr. Sparks was formerly employed in the sales department of the Western Electric Co., Salt Lake City, Utah.

C. E. DAVIES has been appointed managing editor of *Mechanical Engineering*, the journal of the American Society of Mechanical Engineers, to succeed the late L. G. French. Mr. Davies has been associate editor on this publication for over a year.

GEO. A. IRONSIDE, formerly chief operator and maintenance engineer of the Akitiki Power and Paper Co., Iroquois Falls, Ont., Canada, has become assistant superintendent of the Hydroelectric Power Commission, Cameron Falls, Nipigon, Ont.

W. J. COCHRANE, who has been doing maintenance and electrical construction work with the Canadian General Electric Co., Ltd., Toronto, Ont., has entered the consulting field. He is now a partner in the firm of Fitzgerald & Cochrane, consulting machinery engineers, Hamilton, Ont.

JOHN N. WALLACE of Wellington, New Zealand, representative of the Western Electric Co, Ltd., in Australasia for years, has severed his connections with that company and is now seeking connections with manufacturers of road-making and contractors' as representative for Australasia.

G. H. WIRTH has entered the employ of the Federal Board for Vocational Rehabilitation, as instructor in engineering subjects. He is located at U. S. P. H. Hospital-49, Philadelphia, Pa. Mr. Wirth was previously superintendent of construction with the Bainbridge Electric Co., Philadelphia.

FRANK L. DALAS, who has been in Mexico for some months, is at present installing a hydroelectric plant of 1000 h. p. for a sugar plantation in Zapotiltic, Jal., Mexico. Mr. Dalas has had a varied experience in electrical construction work since 1912, when he was graduated from the Carnegie Institute of Technology. Three years of this were spent in Upper Burma, where he was with the Burma Mines, Ltd., engaged in the erection of power lines and substations.

WILLIAM KENDRICK HATT, professor of civil engineering and director of Materials Testing Laboratory, Purdue Uni-

versity, Lafayette Ind., has been engaged as director by the Advisory Board on Highway Research, of the National Research Council. Director Hatt began his duties on July 1. The Advisory Board was established by the Division of Engineering of National Research Council, with the cooperation of Engineering Foundation, as a result of a conference held in New York last November, attended by many representatives of national engineering societies and industries interested in highways, as well as government highway departments and universities. These organizations are ready to give their cooperation to the highway research work, which is now placed on a national basis. Director Hatt's office is located in the building of the National Research Council, 1701 Massachusetts Avenue, Washington, D. C.

OBITUARY

Bertram Dewitt Wilber, of Indianapolis, died on June 9, 1921. Mr. Wilber was born in Big Rapids, Mich., and was graduated from the University of Michigan in 1899. For a short time after that he was employed by the Western Electric Company, of Chicago, leaving this for the Illinois Division of the Central Union Telephone Company. In 1905 he went to Indianapolis with the same company, and in 1911, was appointed state engineer of the Indiana Division of the Company, holding this office until April, 1920. He then became engineer of the Bell Telephone Company, which position he held at the time of his death. Mr. Wilber was a golf enthusiast, being amateur Indiana State golf champion in 1917, and city champion of Indianapolis in 1917 and 1919. He joined the Institute in 1912.

Albert Taylor, manager of the North Atlantic District of the Electric Storage Battery Company, died suddenly on July 6, 1921, in New York. Mr. Taylor was born in Liverpool, England, February 6, 1864. He was graduated from Princeton University in 1884, and after serving an apprenticeship with the Edison General Electric Company, joined the United States Electric Company, which later became a part of the Westinghouse Company. Entering the employ of the Stanley Electric Manufacturing Company, Pittsfield, Mass., in 1890, Mr. Taylor remained there for eight years, after which he was associated with the Electric Storage Battery Company, first as a salesman in the New York Office, then assistant manager and soon manager. Upon the division of the company's territory into five districts in 1920, he was selected as manager of the North Atlantic District. Mr. Taylor was well-known in the electrical industry, especially in central station and telephone fields, and his character won him many friends. He joined the Institute in 1901. He was also a member of the Engineers Club, Lawyers and Lotos Clubs of New York, and the Wykagyl Country Club of New Rochelle, N. Y.

Wilson Lee Campbell, general superintendent of the Automatic Electric Company, Chicago, and a Fellow of the Institute, died at Newton, Iowa, May 28, 1921. Mr. Campbell had been in poor health for about eighteen months previous to his death, but he continued his active duties so far as possible. Born in Muscatine County, Iowa in 1874, Mr. Campbell received his technical training at the Iowa State College, from which he was graduated in 1894. Entering the factory of the Strowger Automatic Telephone Exchange of Chicago in 1895, he started on his life work, the development and production of automatic telephone equipment. In that same year he became superintendent and engineer of the Merchants Mutual Telephone Company of Michigan City, Ind., and two years later was made superintendent of the Augusta Telephone & Electric Company of Augusta, Ga. In 1903 he entered the employ of the Automatic Electric Company of Chicago, as an expert on automatic telephone switchboards, and in 1908 became general superintendent of the company, holding this position until his death. Mr. Campbell contributed many valuable articles to engineering literature on the subject of the automatic telephone. He was a man of wide interests and keen sympathies, with a scientific point of view and impartial judgment which, with his enthusiasm, made him a dominant figure in the practical field of engineering.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (JUNE 1-30, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Electrical Machinery

By T. A. Annett. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 431 pp., illus., 8 x 5 in., cloth. $3.00.

This course of study in industrial electricity is intended for home students and men engaged in the practical operation of electrical machinery. The author has made a special effort to present the subject in such a way that the student will avoid the difficulties which frequently occur in comprehending certain elementary laws, and to have all problems deal with things that occur in daily work.

Much of the text appeared in "Power," as part of a series of articles entitled "The Electrical Study Course."

Engineering Instruments and Meters.

By Edgar Griffiths. N. Y., D. Van Nostrand Co., 1921. 360 pp., illus., diagrs., 10 x 7 in., cloth. $7.50.

The writer has attempted to give a brief review of the appliances which have been devised for the measurement of some of the fundamental quantities of mechanical science, such as length, screw threads, area, volume, velocity, force, mass, work and temperature. The book should enable the reader to appreciate the advantages and drawbacks of the various types of instruments for making any particular measurement, and to choose the instrument best suited to his requirements. References to the literature accompany each chapter.

ENGINEERING OF POWER PLANTS.

By Robert H. Fernald and George A. Orrok. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 595 pp., illus., tables, 9 x 6 in., cloth. $5.00.

This is an epitome of the subject arranged for classroom use, in which an especial effort has been made to awaken a realization of the fact that engineering, although based on exact sciences, is not in itself an exact science, but requires the application of judgment; and to give the student some idea of the commercial side of engineering. The present edition includes corrections, slight modifications and reasonable additions.

FOUNDRYWORK.

By Ben Shaw and James Edgar. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitmans' technical primers.) 115 pp., illus., 6 x 4 in., boards, $1.00.

This little book is intended to supply engineers responsible for the designing machines that involve castings with some knowledge of the fundamental principles applied to their production in the foundry, in order that the difficulties involved in the casting of intricate forms may be understood by the designer and avoided in the design when possible.

GASOLINE AND OTHER MOTOR FUELS.

By Carleton Ellis and Joseph V. Meigs. N. Y., D. Van Nostrand Co., 1921. 709 pp., diagrs., 9 x 6 in., cloth. $10.00.

The authors of this work have endeavored to prepare a substantially complete survey of the field, which would include a description of practically every process of making gasoline and of most other motor fuels of prominence or promise.

The chief fuels considered are gasoline, benzine, alcohol and shale and asphalt oils. Much attention has been given to patent literature.

THE HIGH COST OF STRIKES.

By Marshall Olds. N. Y. and Lond., G. P. Putnams Sons, 1921. 286 pp., 8 x 6 in., cloth. $2.50.

In this book the author has attempted to analyze the costs to the public and to labor itself of the strike epidemic which followed the war and to show, as concretely as possible, the results, to labor and the whole country, of the theories of the professional labor leader as they become apparent in this large scale demonstration. He endeavors to make clear the wasteful absurdity of strikes as a means of controlling the division of the proceeds of production, and suggests other measurements for adjusting labor questions.

INDUSTRIAL ORGANIZATION AND MANAGEMENT.

By Hugo Diemer. Chicago, La Salle Extension University, 1921. 291 pp., illus., 8 x 6 in., cloth. $3.00.

Contents:—The Principles of Business Organization.—Types of Organization.—Locating an Industry.—Manufacturing Plants and Equipment.—Buying.—Receiving, Storing and Recording Materials.—Planning.—The Determination of Costs.—Methods of Collecting Material and Labor Costs.—The Distribution of the Expense Burden.—Standardization.—Scientific Management.—Time and Motion Studies.—Wage Systems, Welfare and Betterment Work.—Employment Problems.—Reports to Executives.

The contents illustrate the general purpose and scope of this book. The volume is intended for beginners and sets forth the elements of the subject clearly and concisely.

LICHTTECHNIK.

By W. Bertelsmann, and others. Edited by L. Bloch. Munchen and Berlin, R. Oldenbourg, 1921. 591 pp., illus., tables, 10 x 7 in., paper. 118M.

This volume embodies the substance of a series of lectures on illumination, delivered in September, 1920, at the Technical High School Charlottenburg, under the auspices of the Deutsche Beleuchtungstechnische Gesellschaft. The lectures were given by experts in various subjects. They discuss such questions as the theoretical bases of light production, photometry, hygiene of lighting, electric lamps, gas lighting, lighting with solid and liquid fuels and acetylene, reflectors and fixtures, organizations of lighting projects, lighting for streets, dwellings, halls, photography, etc. Current practise is followed throughout.

THE MANUFACTURE OF PULP AND PAPER: Volume 2.

By J. J. Clark and T. L. Crossley. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 182 pp., illus., 9 x 6 in., cloth. $5.00.

This is the second volume of the series of textbooks prepared under the direction of the educational committees of the pulp and paper association of the United States and Canada, as a course of study bringing together the fundamental facts of mathematics and elementary science and the principles and practise of paper and pulp making. The present book is devoted to mechanics, hydraulics, elementary electricity and chemistry. It is adapted for home study as well as for classroom instruction.

PHILOSOPHY AND THE NEW PHYSICS.

By Louis Rougier. Authorized translation by Morton Masius. Phila., P. Blakiston's Sons & Co., 1921. 159 pp., 7 x 5 in., cloth. $1.75.

The recent remarkable developments of physical theories, says the translator of this little book, cannot fail to have far reaching influences in philosophical thought. Physicists as a rule, are too much occupied with their special fields to give attention to matters of more general philosophical interest, and few philosophers possess the knowledge required for discussing and criticizing fruitfully the work of the physicist. Professor Rougier's very wide reading in physics has enabled him to present and interpret the new advances in physics in a way which should prove of interest to both philosopher and physicist.

RUBBER MANUFACTURE.

By H. E. Simmons. N. Y., D. Van Nostrand Co., 1921. 149 pp., illus., 11 x 8 in., cloth. $4.50.

This work is intended as a brief but complete survey of the rubber industry, from the methods in use for collecting rubber to the processes used for making rubber goods. The apparatus used in all parts of the industry is described.

DIE SYMBOLISCHE METHODE ZUR LOSUNG VON WECHSELSTROMAUFGABEN.

By Hugo Ring. Berlin, Julius Springer, 1921. 51 pp., 9 x 6 in., paper. 12M.

The symbolic method for the solution of alternating-current calculations has not had the adoption that, in this author's opinion, it deserves. He has therefore prepared this brief monograph to explain the method and to show its possibilities by practical illustrations of its application to the calculations usually needed by engineers engaged in heavy-current work.

TELEPHOTOGRAPHY.

By Cyril F. Lan-Davis. Second edition., by L. B. Booth. Lond., George Routledge & Sons, Ltd.; N. Y., E. P. Dutton Co., 1921. 116 pp., illus., plates, 7 x in., cloth. $2.00.

The book expounds the theory of telephotography, describes the commerical lenses and gives the practical methods in careful detail. The various applications are fully illustrated.

THE THIRD POWER KINK BOOK.

Compiled by the editorial staff of *Power*. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 264 pp., illus., 9 x 6 in., cloth. $1.50.

A collection of some three hundred unconventional but practical ways of meeting power plant emergencies, of the kind that arise in operation and in repair work.

THOMAS' REGISTER OF AMERICAN MANUFACTURERS.

Twelfth edition, 1921. N. Y., Thomas Publishing Co., 12 x 10 in., cloth. $15.00.

The twelfth edition of this popular directory of manufacturers and dealers presents no novelties in arrangement or contents. According to its publishers, however, over 200,000 changes have been made in order to keep the lists complete and accurate.

The Register is a directory of first hands in all lines, classified under several thousand subjects and fully indexed, so that the makers of any article may readily be found. Companies are also listed alphabetically, with data upon branch offices, capital, location, etc. A list of trade names is given, showing the owners of the various trade marks. In addition to these main divisions, the Register also contains lists of representative banks, commerical organizations, exporters and importers, and trade papers, making it a most complete work of reference for buyers and sellers.

WIRELESS TELEGRAPHY WITH SPECIAL REFERENCE TO THE QUENCHED-SPARK SYSTEM.

By Bernard Leggett. N. Y., E. P. Dutton & Co., 1921. (The Directly-Useful Technical Series.) 485 pp., plates, illus., 9 x 6 in., cloth. $12.00.

Although the quenched-spark system and the original Telefunken system have been extensively adopted in America, Australia, Asia and Germany, there is, the author states, no book in English which gives more than a mere outline of them, and much of the apparatus has never been illustrated and described in English. This volume is intended to fill the gap by providing a treatise on radiotelegraphy in which particular attention is given to the quenched-spark system. Bibliographies are appended to many chapters.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—June 22, 1921. Paper: "Interconnection Problems." Author: Mr. L. G. Tighe, Superintendent of Distribution, Northern Ohio Traction & Light Co. Attendance 30.

Cleveland.—May 17, 1921. Cleveland Engineering Society Club Rooms. Annual Dinner, followed by election of officers as follows: Chairman, I. H. Van Horn; Secretary-Treasurer, G. B. Schneeberger; Chairman Papers Committee, L. D. Bale. Subject: "Some Recent Developments in Scientific Research." Speaker: Mr. C. F. Ketering. Attendance 158.

Ithaca.—June 4, 1921, Montour Falls, N. Y. Subject: "Electrical Features of Cranes and Hoists." Speaker: Mr. James A. Shepard. Attendance 40.

Lynn.—June 15, 1921, G. E. Hall. Business meeting and election of officers as follows: Chairman, F. J. Rudd; Vice-Chairman, J. W. West; Secretary-Treasurer, D. F. Smalley; Assistant Secretary, W. M. Howe. Following the business meeting a social hour was enjoyed, the American Tel. & Tel. Co. exhibiting three interesting reels covering various phases of telephone work including wireless telephony. During the showing of the reels there was a wireless telephone instrument set up in the hall and demonstrated to the members. Attendance 250.

Milwaukee.—June 20, 1921, Blatz Hotel. Election of officers as follows: Chairman, Franklin J. Mayers; Secretary, Henry N. Wade.. Attendance 62.

Pittsburgh.—June 7, 1921, Fort Pitt Hotel. Election of officers as follows: Chairman, H. W. Smith; Secretary, E. C. Stone; Executive Committee, Messrs. J. C. Damon, L. R. Fox, B. C. Dennison, J. F. Peters, O. Needham, A. L. Broomall and E. G. Peterson. Following the business Mr. C. E. Skinner gave a talk on his trip to Europe in connection with the International Electrotechnical Commission. A social smoker followed at which new members were welcomed. Attendance 90.

Portland, Ore.—May 24, 1921, Blue Bird Inn. Election of officers as follows: Chairman, W. C. Heston; Secretary, D. W. Proebstel; Executive Committee, Messrs. R. R. Robley and J. E. Yates. The rest of the evening was given over to an informal dance. Attendance 113.

Rochester.—May 27, 1921, Eastman Building, University of Rochester. Election of officers as follows: Chairman, Sydney Alling; Secretary and Treasurer, A. M. Stetler; Executive Committee, Messrs. H. C. Ward, F. T. Byrne, G. A. Scoville and F. J. Stevens. Dr. J. R. Murlin and Dr. Harry Clough, of the University of Rochester, were the speakers of the evening. Dr. Murlin described many of the uses of electricity in physiology and medicine. He demonstrated the method of muscular stimulation by means of low voltage electric current, and also described electrical methods for measuring body temperatures. Dr. Clough described the development of the cardiograph and concluded his talk by a laboratory demonstration, Mr. C. T. Wallis being the subject. Attendance 40.

San Francisco.—May 27, 1921, Engineers' Club. Subject: "220,000-Volt Transmission." Speaker: Professor Harris J. Ryan, of Stanford University. Attendance 99.

Spokane.—May 20, 1921, Davenport Hotel. Election of officers as follows: Chairman, B. M. Merrill; Vice-Chairman, L. J. Posposil; Secretary-Treasurer, H. L. Melvin; Executive Committee, Messrs. D. F. Henderson, J. W. Hungate and James McNair. Subject: "Skagit River Power." Speaker: Mr. C. F. Uhden, Chief Engineer, Skagit River Power, City of Seattle. Attendance 70.

Syracuse.—May 20, 1921, Assembly Hall, Onondaga Co. Court House. Reelection of present officers. Subject: "Radio Telephony." Speaker: Dr. W. H. Nichols, of the Western Electric Laboratories. Attendance 175.

Worcester.—June 16, 1921, Worcester Polytechnic Institute. Business meeting and election of officers as follows: Chairman, George M. Hardy; Vice-Chairman, Francis J. Adams; Secretary-Treasurer, Dean J. Locke; Executive Committee, Messrs. Carl D. Knight, H. O. Tilton, and L. E. Pierce. Attendance 25.

PAST BRANCH MEETINGS

School of Engineering of Milwaukee.—June 17, 1921. Election of officers as follows: Chairman, F. P. Kasparek; Vice-Chairman, A. J. Ackermann; Secretary, L. F. Berg; Treasurer, Peter Stathas. Attendance 44.

Montana State College.—June 8, 1921. Election of officers as follows: Chairman, W. W. Husemeyer; Secretary R. D. Sloan. Attendance 28.

State College of Washington.—June 10, 1921. Election of officers as follows: Chairman, Julian O. Swanson; Vice-Chairman, Harry L. Garner; Secretary, Roy E. Kratzer; Treasurer, Hugh Allan; Reporter, Harold Vance. Subject: "Pointers for Student Engineers." Speaker: Mr. Dana. Attendance 16.

University of Washington.—June 7, 1921. Banquet at the University Commons. Mr. Lawrence Berg acted as toastmaster. Talks were given by Messrs. E. Axman, Nels Mattson, and W. Watson, graduating seniors, Mr. F. W. Budden, ex-Chairman, and Dr. C. E. Magnusson, Dean of the College of Engineering. Music was furnished by a four piece orchestra. Professor Harry E. Smith gave a talk on Industrial Insurance and the Workmen's Compensation Act. Attendance 37.

ADDRESSES WANTED

A list of members whose mail has been returned by the postal authorities, is given below, together with the address as they now appear on the Institute's records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—R. Coelho, 201 West 95th St., New York, N. Y.
2.—F. G. Doane, Box 168, Groton, Conn.
3.—W. F. Gantvoort, Kedongsarie 84, Soerabaia, Java, Dutch East Indies.
4.—L. E. Given, 72 West Adams Street, Room 634, Chicago, Ill.
5.—Conrad Jackson, Hood River, Oregon.
6.—J. M. Keller, Box 121, Sparrows Point, Md.
7.—Harry P. Meyer, 327 East 61st Street, Los Angeles, Cal.
8.—Basil B. Pilcher, 691 East 230th Street, New York, N. Y.
9.—M. J. Pouillon, 95 Straps Street, Ghent, Belgium.
10.—Fumiya Sakuma, Box 26, Terminal, Cal.
11.—Albert G. Scholer, Dundee Lake, N. J.
12.—Frank N. Tucker, 551 East 40th Street, Chicago, Ill.
13.—J. F. Warris, U. S. S. S-3, Union Iron Works, San Francisco, Cal.
14.—Martin Tracy, Tunnel Camp, Brittania Mines, Howe Sound, B. C., Canada.
15.—Harry Wilson, J. G. White Engg. Corp., Marcus Hook, Pa.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

ASSISTANT PROFESSORS, two, in Electrical Engineering Department. Location Georgia. X-268.

EASTERN TECHNICAL SCHOOL has opening for instructor in electrical machinery laboratory. Young men, graduates of a four years electrical or mechanical engineering course with some practical or teaching experience preferred. Opportunity for advancement excellent. Reply stating age, education and training, experience and salary desired. Location Boston, Mass. X-622.

INSTRUCTOR in electrical engineering to handle, principally, laboratory courses. Must have had experience as an assistant, or instructor, in a good laboratory. Additional testing experience with a manufacturing company is desirable. Location North West. X-629.

ILLUMINATING ENGINEER experienced for field work. Must have been doing this kind of work. Location New Jersey. X-674.

SALES ENGINEER preferably Electrical Engineer who understands arc lights and carbon installation. Carbons will be sold to moving picture house. X-684.

SALES ENGINEERS who have sold Mazda Lamps, lighting fixtures and motors. Two men needed. Drawing account and commission. Location vicinity New York City. X-685.

ELECTRICAL DRAFTSMAN, not over 45 years of age with several years' experience on designing of switchboards, substations and wiring diagramming. Location Pittsburgh. X-694.

JUNIOR SALESMAN to start in on the basis of a small salary plus a small commission. Position open after July 6th. Applicants must be of good personal appearance and of course must be over 21 years of age. Location New York City. X-699.

INSTRUCTOR for Electrical Department of prominent college in Western Pennsylvania. class room and laboratory work, d-c. and a-c., also special courses in electrical applications. Must have considerable practical experience in such fields as equipment and installation, central station manufacturing, winding storage battery, telephony, etc. Teaching experience desirable but not essential. State fully first letter, education, experience, age, salary expected. X-702.

TECHNICAL GRADUATE, preferably under 35 years of age, thoroughly conversant with principles, design and construction of high-tension high-frequency oscillatory apparatus such as condensers, oscillator, transformers, etc., which practically means a man with more or less wireless telegraphy experience. This apparatus is not used in wireless work of any kind, but circuits are more similar to wireless than any other types of circuits. There is an unlimited field for development as the process is so connected with the treatment of oils as to lead almost certainly, with its development, to revolutionary changes in many present refinery practises. Give details of past experience, present connections, age, present and anticipated salaries, etc. Location Missouri. X-710.

ENGINEER to operate an electrical hydraulic plant. It is not necessary that he know Spanish, though it would be advantageous. Location Central America. X-713.

INSTRUCTOR for Electrical Engineering subjects. Good engineering training and experience. Location Kansas. X-715.

GRADUATE ELECTRICAL ENGINEERS, over 30 years of age. Experience in cable manufacture while desirable is not essential. Location N. J. X-741.

INSTRUCTOR in physics. Only engineers looking for permanent teaching position will be considered. Application by letter only. Location N. J. vicinity New York City. X-742.

HEATING and VENTILATING ENGINEER preferably one who has had actual experience in the design and construction of forced circulation hot water system for scattered buildings. System requires considerable revamping especially in insulation of the underground pipes and a very considerable extension to take care of eight or ten new buildings we are proposing to erect. Location North Carolina. X-744.

POWER HOUSE SUPERINTENDENT for hydroelectric station operating under 280-foot head. Installation consists of two 11,000 h-p. vertical units. Must have had practical experience in operation and maintenance of hydroelectric plants. Prefer also that applicant have some engineering education. Application by letter. Location New York State. X-751.

ASSISTANT IN MATHEMATICS; subjects: Freshman mathematics, college algebra, trigonometry, and analytical geometry. Should have three or four years college mathematics andprefer men who have had some experience as instructors. Would appeal to young men who desire to take up graduate work in mathematics, while, at the same time, teaching enough classes to pay expenses. Send recent photograph and full statement of courses in mathematics studied and credentials regarding experience in teaching and ability in mathematics. Application by letter. Location Middle West. X-753.

INSTRUCTOR wanted for employees' classes in large electric utility corporation. Knowledge of psychological tests and rating scales desirable. Write fully experience and salary required. X-763.

MEN AVAILABLE

ELECTRICAL CONSTRUCTION ENGINEER, technical training, desires position on construction or maintenance work, affording opportunity for advancement. Eight years experience contracting, construction and maintenance. Three years electrical instructor. Two years assistant to consulting engineer. Available July 15th. New York City preferred. Associate A. I. E. E. E-2863.

GRADUATE ELECTRICAL ENGINEER, 1920; age 21; single. Have had experience as lineman with transmission company. At present local manager for same company. Have had much experience with steam engine operation and electric power plant machinery. Would prefer position with a power company. Associate A. I. E. E. E-2864.

ELECTRICAL ENGINEER, B. S. degree; age 21; unmarried. Six months testing experience. Desires connection leading to future responsibility with a power or manufacturing concern. Middle West location preferred. Initial salary immaterial. Available on two weeks notice. E-2865.

TECHNICAL GRADUATE, June 1921. Age 25, desires position with power company. Will go anywhere. Served two years as Lieutenant, Signal Corps, U. S. A. Available at once. E-2866.

ELECTRICAL ENGINEER, technical school graduate; age 32; married, desires position as assistant or chief engineer with large manufacturing corporation or power company, ten years valuable experience in testing, construction, repair, maintenance and operating work. Able to handle men and produce results. Associate A. I. E. E. E-2867.

ELECTRICAL ENGINEER; age 29; single; five years experience in power station and substation design. Familiar with office routine and purchasing of equipment. Two years experience steam engineering in the U. S. Navy as Lieutenant. Desires engineering or operating position. Employed, but desires change. Location immaterial. Associate A. I. E. E. E-2868.

PROFESSOR electrical engineering, member A. I. E. E. At present connected with a well-known school of engineering. Desires responsible position in a strong engineering school. Capable of directing department. E-2869.

AGENCIES FOR GREAT BRITAIN AND CONTINENT sought by graduate electrical engineer with partner, 14 years practical experience in U. S., England and Continent, both in the commercial and designing line of the industry, residing in England since 1914. Having extensive connections among buyers. Capable of handling schemes of any magnitude. E-2870.

ELECTRICAL ENGINEER, technical graduate; age 32; married. Eight years experience in power plant substation, underground distribution, lighting and industrial engineering. Capable of securing good men, handling men and building an efficient organization. Available within two weeks after an agreement. Best of references furnished. E-2871.

BUSINESS MEN. Position wanted on staff of financial, underwriting, or analytical organization to investigate commercial, technical and scientific soundness of industrial public utility and other business enterprises. Executive of broad business experience. E-2872.

MECHANICAL AND ELECTRICAL ENGINEER, technical graduate, two years shop, and one year general engineering, seeks connection with exporting firm or any cooperation dealing with American machinery trade in the Orient. E-2873.

ELECTRICAL ENGINEER, Assoc. A. I. E. E. Capable of advancing, desires change. Railroad preferred, sixteen years electrical experience not including seven years apprenticeship served in England. At present employed as chief electrician for a Southern railroad. Plenty of pep and executive ability. Would consider foreign offer. Salary can be mutually arranged. Available within 30 days. E-2874.

ELECTRICAL CABLE WORKS ENGINEER. Member A. I. E. E. Assoc. Mem. I. E. E. Three years works manager and five years chief electrician of large European cable factory. Sixteen years extensive cable experience in all. Familiar with estimating, manufacture, testing and laying, seeks responsible position in either factory or commercial side. Minimum basis $5000. Age 34. E-2875.

TECHNICAL GRADUATE; age 28; desires position as electrical engineer or assistant with central station company or constructing firm. Has had 6½ years experience in testing, construction and engineering. Available immediately. East or Middle West preferred. E-2876.

STEEL MILL ELECTRICAL ENGINEER with nine years broad practical experience in steelmills, foundries, blast furnaces, and coke plants, and thorough knowledge of the construction, installation, maintenance and operation of machinery used in and around such plants. Married; age 31; Assoc. A. I. E. E. Best of references; immediately available. E-2877.

GRADUATE ELECTRICAL ENGINEER; age 24; unmarried. Three years experience in automotive and machine design and drafting. Six months concrete construction. References. Desires connection with concern engaged in construction of plant installation. Location no object. E-2878.

ELECTRICAL ENGINEER; age 32; graduate of Yale, desires position with industrial firm preference for electrical apparatus or applicances. Experience, G. E. Test and engineering, street railway operation, electrical design and construction, production inspection and purchasing. E-2879.

GRADUATE ELECTRICAL ENGINEER of 1918, desires connection with industrial, engineering or power company. Experience in power plant and substation work, also in the installation and maintenance of motors for electric hoisting machinery and steel mill work. One year with Signal Corps in France. Single; age 26; Assoc. A. I. E. E. E-2880.

DESIGNING ENGINEER, member A. I. E. E. with wide and varied experience in designing of induction motors, synchronous motors, alternators and fractional horse power direct-current motors, would like to connect with a progressive concern. E-2881.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate; age 28; married, now engaged in steam power plant work in Hawaiian Islands, would like to connect with some firm doing this work in the Phillipines or the Orient. Experienced in the design and construction of complete steam-electrical power plants up to 5000 kv-a., and electrical substations. Available October 1st. Two year contract with transportation from San Francisco. Minimum salary $4200. E-2882.

MECHANICAL ELECTRICAL ENGINEER, inventor designer, extensive shop experience and well developed mechanical judgment. Qualified as an expert to undertake research, invention, design and preparation for manufacture of electromechanical and automatic devices or as a consultant or instructor. Position of responsibility, salary consistent with service desired. Available on short notice. E-2883.

GRADUATE ELECTRICAL ENGINEER, Assoc. A. I. E. E. age 28, seven years experience in charge of electrical maintenance and installation in various factories in this vicinity, one year teaching in State Trade School, and one year consulting service. Salary desired $5000; location preferred, New England or New York, although others considered. E-2884.

MACHINIST by trade. Five years experience in design, test, construction and operation of electrical installations. Three years sales engineer large oil company. At present employed in large industrial plant as designer. Available on short notice. E-2885.

ELECTRICAL ENGINEER wants opportunity in Washington State preferably Spokane; Cornell 1911; construction and operating experience large railway and interurban systems; entire charge substations construction; hydroelectric and steam plant experience; purchasing agent for erection large factory, power plant and equipment; successful salesman; wants engineering or sales representation. E-2886.

ELECTRICAL MECHANICAL ENGINEER. Technical graduate; twelve years practical experience, six being in design, construction, operation of steam power and industrial plants; includes substations, overhead and underground transmission systems. This covers estimating, specifications, purchasing and supervision of design and drafting. Available immediately. Salary $3900. E-2887.

YOUNG MAN, age 24, desires position where following will prove of value. Two years electrical construction work such as installing small power switchboards, motors, generators, lighting circuits, etc. Would prefer position in armature winding or motor repair shops. Graduate of N. Y. E. S. Available immediately. Would also accept factory maintenance job. E-2888.

GRADUATE ELECTRICAL ENGINEER, age 36; single, with fifteen years experience on electrical tests and construction will be available about September 1st. Has just completed the installation of the electrical equipment for a steel tube mill with a connected motor load of approximately 5000 h. p. the motors ranging in capacity from 1200 h. p. to fractional h. p. Best of references from past and present employers E-2889.

ENGINEER, age 28; graduated abroad. One year University courses in U. S. and three years experience abroad in electrical engineering, desires position with operating or construction company, with opportunity for experience. Interested in electric traction and hydroelectric development. E-2890.

ELECTRICAL ENGINEER. Ten years experience in design, construction and operation of hydroelectric stations and electrical equipment for large industrial installations. Age 32; seeks position offering great enough opportunities to warrant permanent residence. Available on short notice Excellent references. E-2891.

ENGINEER DESIRES TEACHING POSITION. University North Dakota, Cornell University; age 41; married. Taught mechanical drawing, descriptive geometry, electrical engineering and laboratory. Eight years practical engineering experience. Location New York City or Middle West. E-2892.

PROFESSORSHIP OF ELECTRICAL ENGINEERING. Taught in large university for fifteen years electro-magnetic theory, d-c. and a-c. practise, transient phenomena, radio telegraphy, etc. In charge of important engineering operations during the war (Major). Now on engineering research. Desires suitable position in University with increasing research activities. E-2893.

RECENT GRADUATE ELECTRICAL ENGINEER; age 27. Four years practical experience in marine electrical work and one year with steam railroad. Position desired with some well established electrical concern wanting a man with practical and technical knowledge. Location U. S. Salary $1800 to start. E-2894.

CONSTRUCTION AND PLANT ENGINEER. Technical graduate, 1911. Fourteen years broad general experience in construction, operation and maintenance and management of power systems and industrial plant equipment. Good general business training and experienced in handling men. Can plan layout, purchase material, take entire charge of construction and produce first class work. Traveled widely, speaks Spanish, makes best use of material and men available, does trouble shooting and emergency repairs and keeps things running. Now employed, salary $3000. Age 34; wife and child. Taking Alexander Hamilton Institute course. Desires permanent position with first class concern in the West. No objection to isolated location, salary governed by location and opportunities. Available at short notice. E-2895.

EXECUTIVE AND INDUSTRIAL ENGINEER or sales engineer for Puget sound territory to manage branch factory or sales. Excellent training and experience. E-2896.

ELECTRICAL CHIEF, age 34; married. Fourteen years supervising experience on electrical installation work in building, also distribution systems, lighting, power and interior communication work abroad all types of government warships, transports, and submarines. Experienced in handling draftsmen, organizing and capable of producing production. Desire position with some established firm where position is permanent and advancement assured. E-2897.

SALES OR CONSTRUCTION ENGINEER. Graduate electrical engineer; age 35; is desirous of locating in the East, vicinity preferably Philadelphia or New York. Twelve years experience in street railway operation and two years sales engineering. Salary $4500. E-2898.

ELECTRICAL ENGINEER; age 34; single; technical graduate. Two years General Electric Company, testing department; two years Public Utility Co., five years research work on automotive equipment, desires position as experimental or research engineer. Assoc. A. I. E. E. and Member American Mathematical Society. E-2899.

GRADUATE ELECTRICAL ENGINEER, 1915 Univ. of Penna. age 28; single. Six years experience in design, construction and operation of high-tension generating and substations, of which four years was in the employ of large public utility and two years in industrial plants. Member A. I. E. E. Location Middle Atlantic States. Salary $3000. E-2900.

RESEARCH ENGINEER, graduate E. E., experienced in research and development of electrical appliances, thoroughly familiar with patents and patent law. About to be registered as patent attorney. Can handle small laboratory or assist in management of large concern. E-2901.

MECHANICAL AND POWER ENGINEER; age 29; single. Technical graduate, B. S. and M. E. Seven years experience along broad lines, chemical manufacturing, machine shop, metallurgy, sugar engineering, industrial and power plant practise and operation, layout, design, calculations, steam, water, air heating and distribution, research, etc. Has business and executive ability and can handle men; desires connection as mechanical engineer, power plant or in similar responsible position. E-2902.

ELECTRICAL ENGINEERING GRADUATE; 1920; single. One year General Electric

test, desires position in sales or public utility work. Available on short notice. Location preferred Southeast. E-2903.

SUPERINTENDENT, mechanical and electrical construction, operation or maintenance. Capable organizer and executive with wide industrial and power plant experience. E-2904.

UTILITY MANAGER desires new connection. Successful operator of several utility properties. Present connection manager in town of 15,000, electric light, power and gas. Considerable experience, power plant improvement and operation. Twelve years experience. Associate A. I. E. E. Available after August 1st. Best references including present employers E-2905.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate. Seven years experience, wants position with firm as operating or maintenance superintendent. Four years with large electrical manufacturer in manufacturing and testing and three years in engineering department of same company, in applying electrical machinery and in making plant surveys for improvements. E-2906.

TECHNICAL GRADUATE; age 30, desires position as assistant to electrical engineer or superintendent. Nine years experience including shop, testing, operating and maintenance work. E-2907.

ELECTRICAL ENGINEER; age 28; Member A. I. E. E., Jr. Mem. A. S. M. E., Chief electrician U. S. N. Nine years service. General foreman of construction and assistant engineer in charge of construction. Ten years practical experience, five years d-c. and five years a-c. Wishes position where chance of advancement. Location anywhere. E-2908.

ELECTRICAL INDUSTRIAL ENGINEER; age 36; with executive ability and broad experience desires to reenter industrial work after teaching electrical engineering subjects for three years. Suitable living conditions for young children essential. Salary based on responsibilities shouldered. Can go to New York for interview. E-2909.

PHYSICIST, Member American Physical Society; Associate A. I. E. E. now in charge of technical physical laboratory; desires position of responsibility in the research or development field of pure or applied physics. New York City or vicinity preferred. E-2910.

YOUNG MAN, university trained in electrical engineering with four years experience in manufacturing, testing and sales of electrical machinery. Work of a commercial nature preferred. E-2911.

EXECUTIVE. Electrical Engineer; four years practical experience power plant engineering, high potential and radio; technical graduate. Exceptionally valuable G. E. Co., test and complaints. One year construction engineer steam turbines and electrical equipment. Available after September 1st. Prefer executive position with opportunity for advancement. Age 27. Present salary $2600. E-2912.

ELECTRICAL ENGINEERING GRADUATE; age 26; married. Four years factory experience; one with hydraulic turbine manufacturer, desires position in West giving experience in preliminary investigation, design or construction of hydroelectric plant. E-2913.

BROWN AND CORNELL UNIVERSITIES (degree from each) age 26; single. Taught electrical engineering, electricity, drawing, heat, and telegraph engineering; desires to teach electrical subjects provided not at all laboratory. E-2914.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1921.

Alonzo, Francisco F., Pittsburgh, Pa.
Allsobrook, Henry L., Columbia, S. C.
Baron, Roberto J. B., Newark, N. J.
Bates, Earl J., Dayton, Ohio
Craig, Albert G., Yonkers, N. Y.
Bugeja, Charles, Brooklyn, N. Y.
Coffin, Charles D., Tyngsboro, Mass.
Davison, George E., Richmond, Va.
de Loache, Robert Lee, Atlanta, Ga.
Eaman, Thomas M., Atlanta, Ga.
Egee, Joseph W., Montgomery, Ala.
Everett, Richard E., Milwaukee, Wis.
Gilder, Thomas N., Portland, Ore.
Goodwin, Ralph J., Dothan, Ala.
Gould, Harold M., (Fellow), Detroit, Mich.
Guidoni, Allessandro, Washington, D. C.
Hatch, Philip H., Pelham Manor, N. Y.
Higuchi, Nagao, (Member), New York, N. Y.
Huang, Young-Tsieh, Philadelphia, Pa.
Jefferson, William E., Norfolk, Va.
Kubach, William L., (Member), Cleveland, Ohio.
Mackay, St. Clair, New York, N. Y.
Marshall, Joseph H., New York, N. Y.
McLaughlin, George S., Pocatello, Idaho
Pioch, Frank H., Montcoal, W. Va.
Schanz, John, Jr., New York, N. Y.
Smart, Lee Roy, Chicago, Ill.
Smith, Charles H., San Francisco, Cal.
Smith, Waldorf A., Rayville, La.
Stecher, Lewis J., Schenectady, N. Y.
Sutton, Porter O., Norfolk, Va.
Thompson, Lawrence F., Salt Lake City, Utah
Tunison, Lester, Los Angeles, Cal.
Vrla, Ralph R., (Member), Rochester, N. Y.
Ward, Richard H., (Member), New York, N. Y.
Williams, H. L., Evanston, Wyoming
Total 34

Foreign

da Costa, Antonio M., Brazil, S. A.
Hall, Jack H., Kauai, T. H.
Hamilton, John, Waikato, N. Z.
Harvey, Frank R., Taihape, N. I., N. Z.
Hayakawa, Tominasa, Tokyo, Japan
Kerr, W. Wallace, Glasgow, Scotland
Macias, Carlos, Mexico, D. F.
Muller, Karl E., Mexico, D. F., Mex.
Raminez, Javier, P., Mexico City, Mexico
Scott, William, Gore, N. Z.
Scop, Lev, Belfast, Ireland
Todd, Robert W., Manchester, Eng.
Wedmore, Edmund B., (Member), London, Eng.
Yamamura, Tadayuki, Kobe, Japan
Total 14

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William McClellan

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A. I. E. E. COMMITTEES

The list of committees and their chairmen is omitted from this issue, as new appointments will be made for the administrative year commencing August 1. The new committees will be listed in the September issue.

A. I. E. E. REPRESENTATION

A complete list of A. I. E. E. representatives on various bodies will be published in the September issue.

A. I. E. E. SECTIONS AND BRANCHES

A complete list of the 42 Sections and 61 Branches of the Institute, with the names of the chairmen and secretaries, will be published in the September issue of the Journal.

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The Magnetron

BY ALBERT W. HULL

Research Laboratory, General Electric Co., Schenectady, N. Y.

Introduction

IN PRESENTING to you this youngest member of the electron tube family, I am both aided and embarrassed by its family history. I am aided by the fact that you are already acquainted with electrons, so that I need waste no time in explanation or argument regarding their existence. You believe in these little cannon balls which jump out of the hot filament, fly across the vacuum, and plunge into the anode. You have seen them heat the tungsten anode of an X-ray tube to its melting-point in a fraction of a second. Most of you believe that when a current flows through a wire it is these same little electrons, and nothing else, that stream through the wire, like water flowing through a pipe.

But while electrons are among your engineering acquaintances, they are not accepted, so to speak. They are associated with wireless magic and micro-amperes, read through a telescope. And so, as engineers, you view them with aloofness, as interesting playthings, not engineering tools.

It is quite reasonable that you should view them so, but you are wrong. Electron devices are not small, they are only young. They are growing up. You have heard of their slow development from micro-amperes to milliamperes. Since you last heard from them they have grown from milliamperes to amperes; and before you know it, before you know *them*, if you don't watch out, they will have grown to kiloamperes.

I therefore present to you, tonight, the magnetron as an engineering device. I shall suggest some applications. You, with your greater experience, can, I hope, think of many more.

I shall first state briefly what the magnetron is; then why it is, that is, the theory of its operation and how it is related to the other "trons"; then what it will do; and, finally, what I hope it will do.

Definition

"Magnetron" is a Greeko-Schenectady name, as Mr. Lee DeForest calls it, for a vacuum electric device which is controlled by magnetic field. It belongs to the kenotron family. Kenotron, which means, as those of you who are Greek scholars will readily recognize, a "thing with nothing in it," is a general term which we apply to all our vacuum thermionic devices. Examples of simple kenotrons are the X-ray tube and

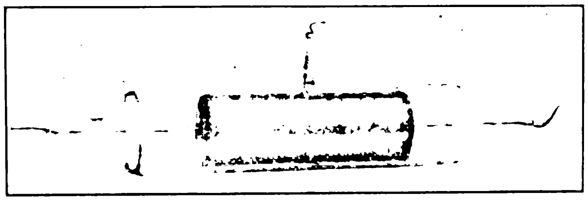


Fig. 1

kenotron rectifier. The name pliotron is intended to mean a thing that amplifies; the dynatron, a thing that generates power; and the magnetron, a thing operated by magnetic field.

Structurally, the magnetron is a simple kenotron whose elements are symmetrical about an axis. It may consist of a straight filament surrounded by a cylindrical anode, as in Fig. 1; or a straight rod-shaped anode, surrounded by a helical filament, as in Fig. 2; or it may consist of three elements, a filament, grid, and anode, all symmetrical with respect to a common axis, as in Fig. 3. Symmetry, circular symmetry with respect to an axis, is essential. The reason for this will appear later. The fundamental distinguishing

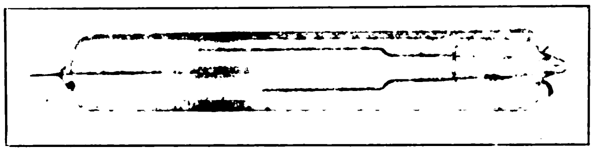


Fig. 2

structural feature of the magnetron is its symmetry.

A second structural characteristic, in addition to symmetry, is essential for a practical magnetron; namely, that it should be of such form that a magnetic field parallel to the axis can be conveniently and economically applied. This is accomplished in the tube shown in Fig. 1 by making the glass envelope a tight

Lecture delivered at the Annual Meeting of the A. I. E. E., New York, N. Y., May 20, 1921.

fitting cylinder, concentric with the electrodes, so that a solenoidal coil may be wound directly on the glass; and by slotting the anode longitudinally, so that the magnetic flux produced by the solenoid will not be neutralized by eddy currents. The slotting of the anode is especially important when high-frequency alternating magnetic fields are to be applied.

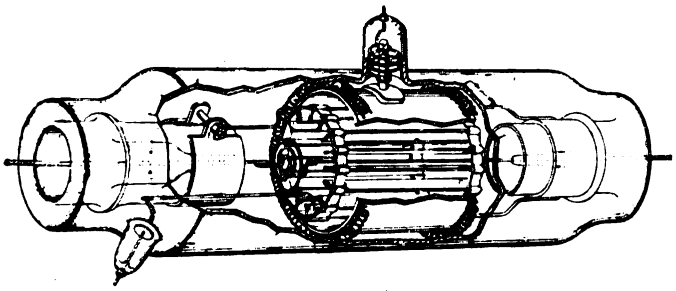


Fig. 3

Electrically, the magnetron is a valve, operated by magnetic field. Its characteristic may be stated as follows: If a constant voltage is impressed between cathode and anode, the current that flows through the tube is not affected by a magnetic field weaker than a certain critical value, but falls to zero if the field is increased beyond this value. The magnetic field must have its lines parallel to the axis of the tube.

This characteristic may be made clear by some examples.

Fig. 4 shows the tube and circuit. The cathode is a straight tungsten filament, the anode a circular cylinder. A battery, B_1, heats the filament to incandescence, and another battery, B_2, impresses a constant voltage between cathode and anode, the anode

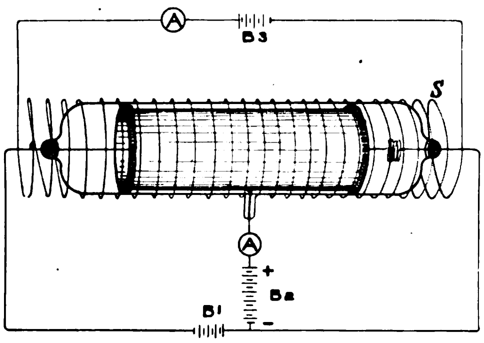


Fig. 4

being positive. This is a plain kenotron arrangement, and if the temperature of the filament is high enough, a current will flow across the vacuum, as you know. The magnitude of the current will be limited either by the temperature of the filament or the voltage of the anode, whichever gives the *smaller* value of current.

The addition of a magnetic field, produced by the solenoid S, imposes a third type of limitation upon the current flow. If the field is weaker than a certain critical value, the full current will flow, limited only by filament temperature or voltage; if the field is stronger than this critical value, no current will flow. The action of the magnetic field is thus similar to that of a valve in hydrodynamics, or a contact relay in electrical circuits. In fact, the same characteristics would be obtained if the tube in Fig. 4 were replaced by a resistance, and the solenoid S, instead of being

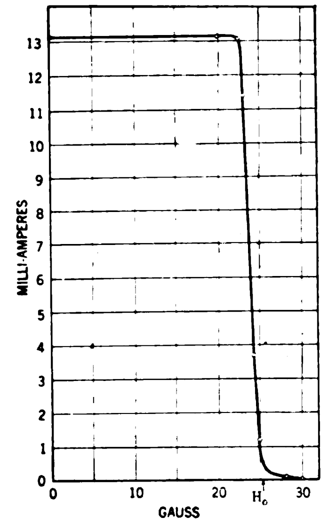


Fig. 5

around the tube, were used to energize a relay that opened and closed the circuit of the battery B_2. As long as the magnetic field is weaker than a certain critical value, the relay remains closed, and full current flows; when the field becomes stronger than this critical value, it opens the relay, and no current flows. The magnetron relay has the advantage of no moving parts and no inertia—its speed is limited

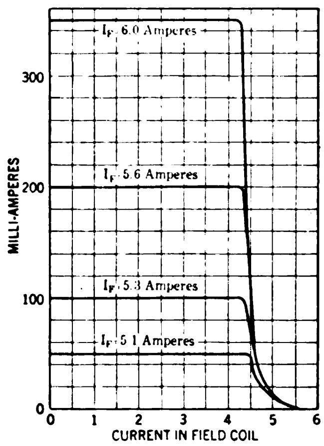


Fig. 6

only by the time necessary to build up the magnetic field, which may easily be made less than one millionth of a second. It has the disadvantage that it is a high-resistance relay, since it requires a vacuum tube in the circuit.

A typical gauss-ampere characteristic is shown in Fig. 5. The abscissas are gausses, or lines per square

centimeter, the ordinates current through the tube. The anode was a cylinder 1½ in. in diameter and 4½ in. long, the cathode a 4-mil straight filament. It is seen that for all values of the magnetic field less than 23 lines per square centimeter, the valve is wide open, and the same current flows through the tube as when the

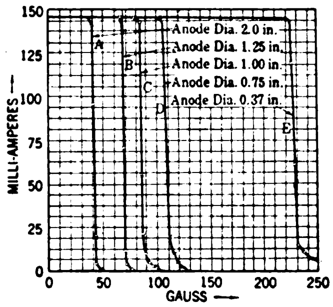


FIG. 7

magnetic field is zero. For fields larger than 25 lines per sq. cm. the valve is closed, and no current flows. It will be noted that the transition from "open" to "closed" condition is not quite abrupt. This is due mainly to lack of symmetry. In a well evacuated perfectly symmetrical tube, the transition should be very nearly abrupt.

In Fig. 5 the maximum current is limited by the voltage between cathode and anode. The effect of the magnetic field is the same, however, whether the maximum current is limited by voltage or temperature. This is shown in Fig. 6, which gives the characteristics of the same tube at four different filament temperatures. In the upper curve the temperature is high enough so that the current is limited only by the volt-

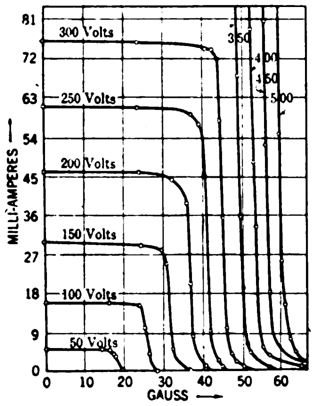


FIG. 8

age. In the other three, the current is limited by the filament temperature.

The critical value of magnetic field that is just sufficient to close the valve depends only upon the diameter of the anode and the voltage across the tube. It is inversely proportional to anode diameter, and directly proportional to the square root of the voltage between cathode and anode. Its dependence on anode diameter is illustrated by Fig. 7, which shows the characteristics of four different tubes, with diameters from ⅜-in. to 2 in., at the same voltage. The maximum currents are limited by filament temperature to the same value. It is seen that the 1-inch diameter anode requires twice as much field as the 2-inch one, and the

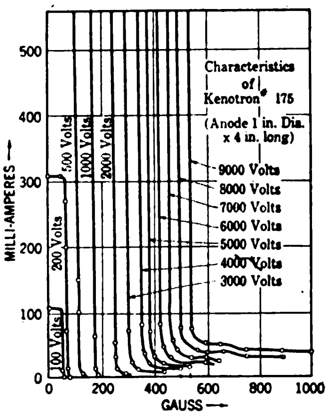


FIG. 9

⅜-in. one twice as much as the ¾-in. one; that is, the critical field is inversely proportional to the diameter.

The effect of varying the voltage is shown in Figs. 8 and 9, which give the characteristics of the same tube at different voltages. The anode in Fig. 8 was a cylinder 2 in. in diameter and 2 in. long; in Fig. 9 a cylinder 1 in. in diameter by 4 in. long. It will be noted that the field required to close the valve at 500 volts is only half as great as at 2000 volts, and one-quarter as great as at 8000 volts; that is the critical field is proportional to the square root of the voltage. Only the lower portions of the curves in Fig. 9 could be taken because of the excessive heating of the anode. The full current at 9000 volts is 100 amperes. This was reduced to a few milliamperes by the magnetic field alone.

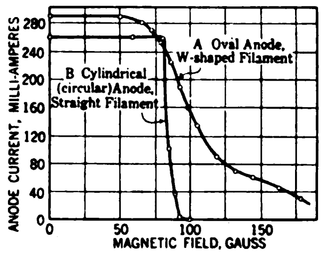


FIG. 10

The necessity for symmetry of construction is shown in Fig. 10. Curve *A* shows the characteristics of a magnetron, with straight filament and cylindrical anode 1 in. in diameter by 4 in. long, at 250 volts; curve *B*, that of a kenotron with *W* shaped filament and oval anode, ¾ in. thick by 1½ in. wide by 2 in. long.

The necessity for making the lines of the field parallel

to the axis of the tube is shown by Fig. 11. Curve *A* shows the characteristic of a 1-in. by 4-in. tube with field parallel to its axis; curve *B* the characteristic of the same tube at the same voltage with the lines of the field at an angle of 20 deg. to the axis of the tube.

A more sensitive form of magnetron may be made by putting the anode inside the cathode instead of outside, as in Fig. 2. The tube and circuit are shown in

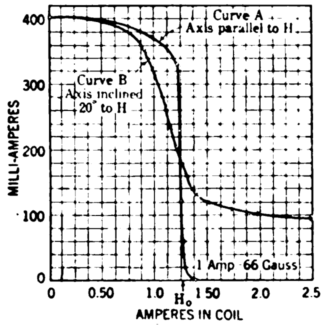


Fig. 11

Fig. 12. The cathode is a helical tungsten filament, ¼ in. in diameter, the anode a straight tungsten wire $^1/_{100}$ in. in diameter. The magnetic field required to operate a magnetron with internal anode is smaller than for an external anode of the same dimensions by a factor equal to the ratio of the diameters of the cathode and anode. In the tube shown in Fig. 12 this ratio is 25, so that the field required to close the valve is only $^1/_{25}$ as great as for a tube of similar dimensions with external anode; *i. e.*, a tube with 10-mil straight filament surrounded by a ¼-in. diameter anode. The cutoff is less abrupt, however, in the internal anode tube.

Fig. 13 shows the characteristic of this tube at 110 volts. A rotating commutator interrupted the heating current during the brief intervals while the

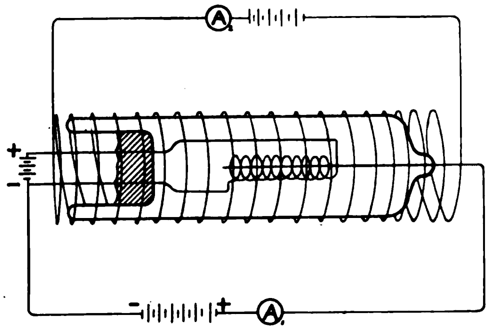


Fig. 12

measurements were being made. At first glance one would say that this characteristic is not steep enough to be of any interest, like that of the unsymmetrical tubes shown in Figs. 10 and 11. It will be noted, however, that the fields required are manifold smaller than in Figs. 10 and 11, so that a field only ten times that of the earth is sufficient to reduce the current to half value, and the effect of the earth's magnetic field is clearly seen, shifting the whole curve to the right by $^6/_{10}$ of a gauss.

The slope of the curve is due to the initial velocities with which the electrons are emitted from the filament. These initial velocities are known, and it is possible to calculate their effect. The crosses in Fig. 13 show the calculated results, the experimental values being represented by the circles. If the initial velocities

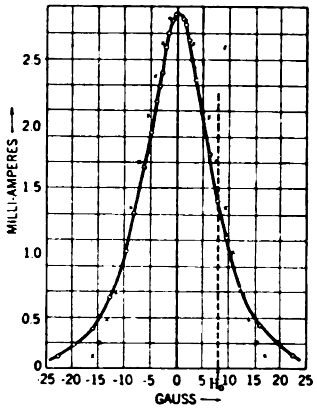


Fig. 13

were very small, the characteristic would be represented by the vertical line H_o. This condition can be approximated by using a very low temperature filament.

Theory of Magnetron

The foregoing discussion has aimed to define what the magnetron is—an inertialess, high-resistance valve, operated by magnetic field. I shall now attempt to explain why it is—the theory of its operation.

The mathematical theory of the magnetron will be found in the Aug., 1921 number of the *Physical Review*. It need be referred to here only to point out that the solutions are simple and apparently rigorous and agree with the experimental facts outlined above.

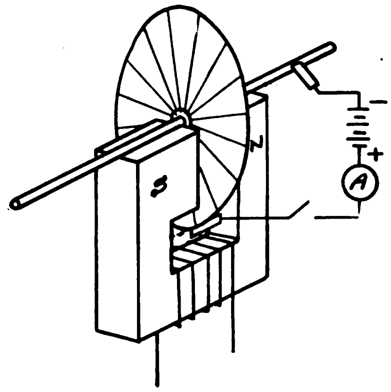


Fig. 14

The operation of the magnetron may best be understood from an analogy.

The magnetron is closely analogous to a direct-current motor running without load. In order to avoid commutators, I shall take the case of a unipolar

motor (Fig. 14), composed of a slotted disk capable of rotating between the poles of an electromagnet. Current is led into and out of the disk by brushes on the axis and periphery respectively. When the switch is closed a large current flows, as indicated by an ammeter A, and the flow of current across the lines of the magnetic field develops a torque which starts the disk in rotation. The rotation develops a back e. m. f., which, if there is no resistance to rotation, will increase until it exactly equals the e. m. f. of the battery, and the current through the ammeter A will fall to zero. In practise the current does not fall quite to zero, because of the friction.

I have described the operation of the motor in ordinary engineering language. I will now describe it again in greater detail, using the language of electrons, but introducing no new ideas. Instead of the simple statement that current flows when the switch is closed, I will be more specific, and say that electrons flow; for it is electrons, and nothing else, that carry electricity through wires, and they flow from negative to positive, in this case from the axis toward the periphery. The disk begins to rotate because a conductor

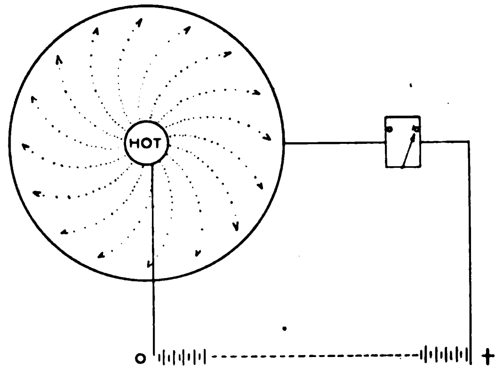


FIG. 15

carrying current in a magnetic field is acted on by a mechanical force. Does the force act on the conductor or the current that is flowing in it? This question may be answered definitely. The force acts on the electrons, tending to make them move in spiral paths instead of radially. Since the electrons cannot move tangentially without taking the disk with them, on account of the slots, the disk begins to rotate. The electrons would drag the disk with them even in the absence of slots because of electric resistance.

The rotating disk carries the electrons with it, giving them a tangential velocity. The electrons will therefore be acted upon by an additional component of force, at right angles to this tangential component of velocity, that is, radially inward, in opposition to the impressed e. m. f. When maximum speed is attained, if there is no friction, the radial flow of the electrons is completely stopped by the back e. m. f. Their motion becomes entirely tangential, and the force acting on them entirely inward, in opposition to the e. m. f. of the battery. We thus have a simple case of a conductor at whose terminals an e. m. f. is impressed by a battery, but no current flows. The explanation of the lack of current is a back e. m. f., produced by the motion of the electrons in the conductor across the lines of magnetic force.

Turning now to the magnetron, which is shown in cross-section in Fig. 15, it is obvious that the electrons that start to move radially outward, under the influence of the impressed e. m. f., will be acted on by

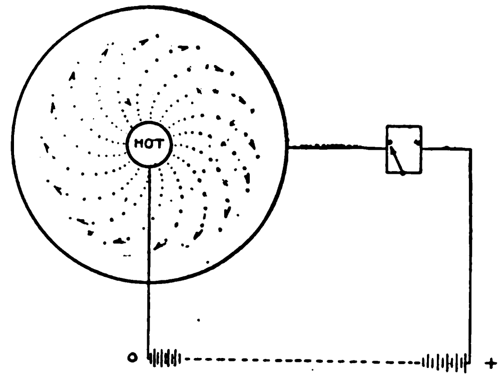


FIG. 16

a tangential force tending to curve their paths into spirals, and that the tangential component of velocity thus imparted will react with the magnetic field (which is normal to the plane of the figure) to produce a radial component of force on the electrons, inward toward the filament, in opposition to the e. m. f. of the battery. If the magnetic field is sufficiently strong as shown in Fig. 16, this inward force, *due to the circular motion* of the electrons, will just balance the e. m. f. impressed by the battery. Hence the electrons, though perfectly free to move about in the vacuum, are unable to reach the anode, even though driven by an e. m. f. of 10,000 volts or more. The back e. m. f. due to their circular motion equals the impressed e. m. f.

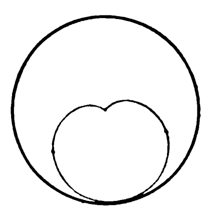


FIG. 17

The question will naturally arise, what becomes of the electrons that are thus left stranded in space? Do they return to the filament, or do they continue to circle around it forever? The answer is simple and definite. They do both. I have obtained a simple solution of their approximate paths, and Langmuir has succeeded, by approximation, in calculating the exact path. It is shown in Fig. 17 and is represented very nearly by the equation $r = R\ (\sin\ 2/3\ \theta)^{3/2}$ The electron flies out as near to the cylinder as it can

go, depending on the strength of the magnetic field, then back to the filament, then out again, etc., *ad infinitum*, or until it strikes a gas molecule or some unsymmetrical part of the tube. The space soon becomes filled with these planets (in less than one one hundred millionth of a second, ordinarily) and their mutual repulsion prevents any more electrons from coming out of the filament.

The magnetron differs from the motor in two important respects:

1. The motion of the electrons is resistanceless and nearly inertialess, so that the back e. m. f. is established instantly when the voltage is applied, and is exactly equal to the applied voltage.

2. There is a critical value of magnetic field below which the back e. m. f. in the magnetron cannot equal

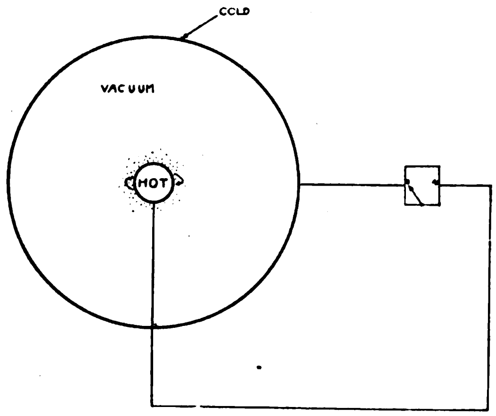


FIG. 18

a given impressed e. m. f., and the valve will not close. For all fields stronger than this critical value, it will close. This critical field is a function of the voltage, and is given by the very simple formula

$$H = \frac{\sqrt{8 \frac{m}{e} V}}{R}$$

or, putting in numerical values for m and e, the mass and charge of the electron, and expressing V, the potential across the tube, in volts, R, the radius of the external anode, in cm., and magnetic field H in lines per cm.[2],

$$H = \frac{6.72}{R} \sqrt{V}$$

Comparison of the Magnetron with other "Trons"

I have called the magnetron a *new* electric valve, for its predecessors, the kenotron rectifier, pliotron, and dynatron are all valves, each one operating on an entirely different principle and with different characteristics. The magnetron thus represents the fourth independent method of controlling the flow of current between metal electrodes in vacuum.

The *kenotron rectifier* exemplifies the control of current from one metal electrode in vacuum to another by the *temperature* of the electrodes. Electrons can pass freely from one atom to another inside a metal, so that the smallest electromotive force that can be applied is sufficient to produce a definite current. When

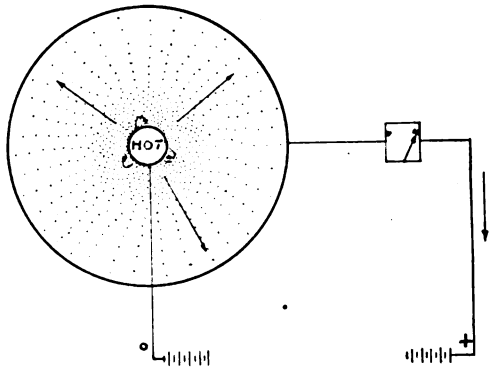


FIG. 19

they come to the boundary of the metal, however, and attempt to jump out into vacuum, they are held back by the attraction of the positive nuclei of the atoms, and can be pulled away only by enormous electric fields, of the order of one million volts per centimeter. A well evacuated tube, containing well rounded cold electrodes one centimeter apart, is thus a perfect insulator for voltages up to approximately one million volts.

When one of the electrodes is heated, however, the kinetic energy of both atoms and electrons is increased, and when sufficiently hot some of the electrons are able to jump out or evaporate, exactly as molecules evaporate from a liquid or solid. I have attempted to illustrate this in Figs. 18 and 19. The evaporating electrons drift across the vacuum to the other electrode, and constitute a unidirectional current. The rate of drift is slow, however, and they get in each

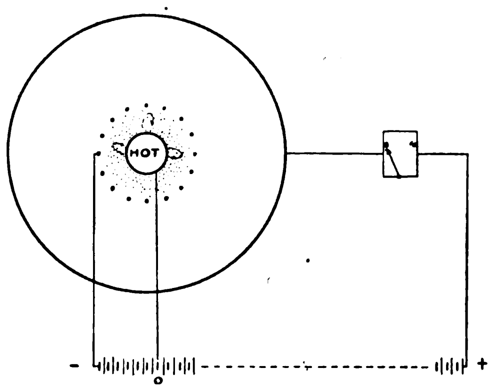


FIG. 20

other's way and cause back pressure, so that the current is very small unless they are aided by an electric field. When once out, their motion may be greatly speeded up by an electric field, and the current thus increased, precisely as evaporation of a liquid is in-

creased by blowing away the vapor as fast as it is formed. Fig. 18 is intended to illustrate crudely the case of no electric field, *i. e.*, when cathode and anode are at the same potential, and Fig. 19 the case when the anode is at positive potential.

Most metals cannot be heated hot enough, without melting, to give an evaporation or "emission" of more than a few milliamperes per square centimeter. Tungsten, however, gives an emission of hundreds of amperes per sq. cm. at its melting point, and a large filament will run for years at a temperature that gives an emission of 1 amp. per cm.^{2}, or 10,000 amperes per square meter of filament surface. For example, a filament one-quarter inch in diameter and four ft. long will operate continuously for years with an emission of 225 amperes, and will operate intermittently with an emission of several thousand amperes. It is thus evident that the kenotron is capable of rectifying very large currents at high voltages.

The rate of evaporation of liquid may be limited either by its temperature or the wind velocity, according to whether or not the molecules are blown away as fast as they evaporate. In the same way the evaporation of electrons may be limited by temperature or voltage, according to whether or not the voltage is able to carry them away as fast as they evaporate. When they are not carried away as fast as they jump out, they pile up in the space around the hot filament and produce a back pressure on those that are trying to follow, forcing them back into the filament. This condition is generally referred to as "space charge limitation"; *i. e.*, limitation of the current of oncoming electrons by the electrostatic repulsion of the electrons present in the space between the electrodes.

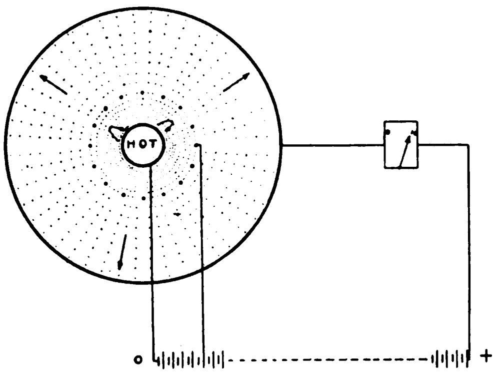


Fig. 21

I have emphasized the idea of *space charge* because it is the principle of operation of the *pliotron*,—the second method of control. In the pliotron the current that can flow from a hot filament to a cold anode is controlled by a grid interposed between filament and plate. The grid acts as an electrostatic screen, shielding the filament from the positively charged anode. The filament temperature is maintained high, so that the current is limited only by space charge, and the space charge limitation is determined by the potential of the grid.

This is roughly illustrated by Figs. 20 and 21. In Fig. 20 the grid is at a negative potential with respect to the filament, and repels the electrons so that they pile up around the filament and prevent any current flow. The valve is closed. In Fig. 21 the grid is positive, and pulls the evaporating electrons away at a sufficient rate to give a large current. The valve is open. Although it is the grid potential that pulls the electrons away from the filament, most of them go through between the grid wires to the anode, and very few strike the grid. Very little energy is, therefore, needed to open and close the valve. The pliotron is an efficient valve.

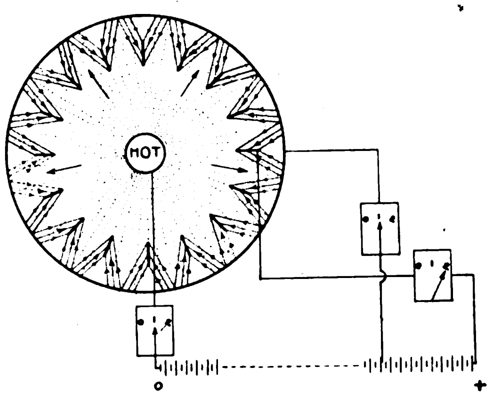


Fig. 22

The third method of control is exemplified by the *dynatron*, and illustrated in Fig. 22. I have explained that electrons cannot be pulled out of a cold metal except by very intense electric fields. They may, however, be *splashed* out by the impact of high-speed electrons on the metal. Each impinging electron may splash out from one to five or more secondary electrons, depending on the speed of impact. The secondary electrons may flow to a more positive anode (in Fig. 22 a grid) and thence through a work circuit; or power may be derived from the secondary cathode or "dynode" itself, since it has the characteristic of a

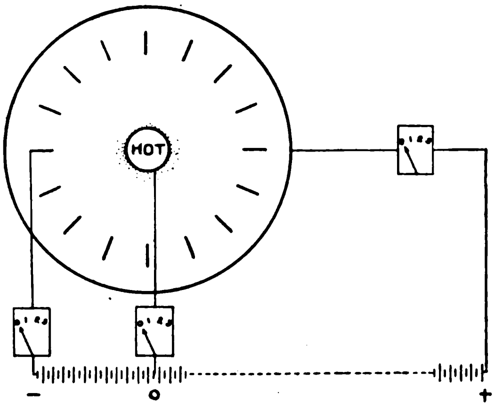


Fig. 23

negative resistance.[1] The production of secondary electrons may be controlled by varying the number and speed of the impinging electrons, and thus the dynatron valve may be opened or closed to any desired degree. The impact excitation of electrons has the advantage over temperature in that it may be turned on or off instantly, while time is required to heat or cool a filament.

The fourth method of control is exemplified by the *magnetron*, as illustrated by Figs. 15 and 16. The

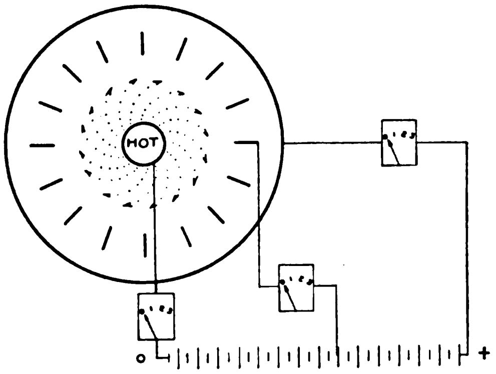


Fig. 24

electrons try to fly straight across from filament to anode. Since they are moving in a magnetic field, they are acted on by a mechanical force equal, in direction and magnitude, to the vector product of their velocity and the magnetic field. This causes them to move in curved paths as shown in Fig. 15. They all strike the anode, in spite of the curvature, as long as the magnetic field strength is below a certain critical value, as in Fig. 15. The valve is wide open. If the magnetic field is above this critical value as in Fig. 16, none of them strike. The valve is closed.

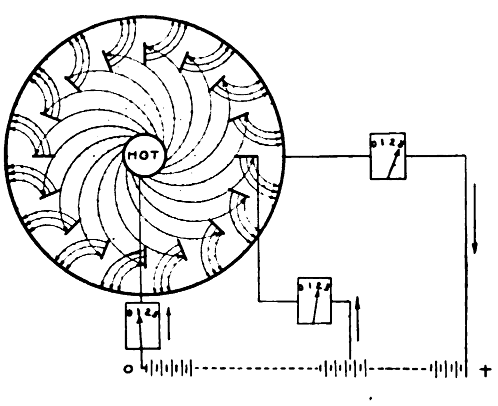


Fig. 25

These four methods of control of current flow in vacuum may be summarized by saying that two of them have to do with getting the electrons out of the metal into vacuum, by *boiling* and *splashing* respectively; the other two with controlling their flow after they are out, by means of *back e. m. f. produced electrostatically and electromagnetically* respectively.

These different methods of control may be combined in the same tube in many different ways. An example is given in Figs. 23, 24 and 25. A work circuit is to be assumed connected externally between grid and anode, and a uniform magnetic field at right angles to the plane of the figure. In Fig. 23 the filament is hot; that is, the primary valve is open; but the electrons are prevented from escaping by the back e. m. f., due to the negative potential impressed on the grid. In Fig. 24 the grid is positive, trying to drag the electrons from the filament, but they are prevented from getting as far as the grid by the back e. m. f., due to their motion in the magnetic field. In Fig. 25 the grid is sufficiently positive so that all the electrons strike it in spite of the magnetic field. These electrons are stopped by the grid. If they strike it with low velocity, that is, if the grid is only a few volts positive, they will produce very few secondary electrons, and hence very little current will flow to the anode. The valve will still be closed. In Fig. 25 the grid potential is assumed to be sufficiently positive so that the impact

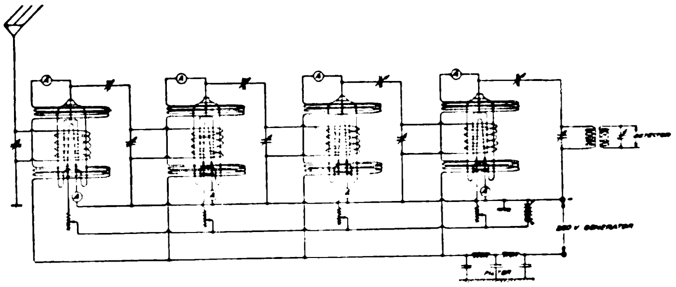


Fig. 26

of the primary electrons on it gives rise to a large number of secondary electrons. These are free to flow across to the anode and thence through the work circuit. The valve is open. It should be noted that, in order to open this valve, all four controls must be open at once—any one of them is sufficient to close the valve.

Applications

In conclusion I will say just a word about applications. The magnetron is so young that its applications are mostly hopes. The only purpose for which it is actually being used is as "synchronous detector" in continuous wave radio telegraphy, in the transoceanic receiving stations of the Radio Corporation.[2] In this case the magnetron acts as a simple high-frequency valve, opened and closed at approximately signal frequency by a locally generated magnetic field, letting

1. For description of the dynatron see *Proc.* Inst. Radio Eng., Vol. 6, pp. 5-36, Feb. 1918.

2. The synchronous detector will be described eleswhere by its inventor, Mr. E. F. W. Alexanderson.

through first the positive peaks of the signal and then the negative, giving an audible tone.

We have experimented with magnetrons as amplifiers, the current to be amplified being used to energize the magnetic field, and the output circuit being in series with the tube and battery. The operation is about the same as that of the pliotron, and the degree of amplification about the same. In a four-tube radio frequency amplifier we obtained fivefold current amplification per stage The circuit is shown in Fig. 26. In these tests the magnetrons used somewhat larger currents than pliotrons, but this is a question of tube and circuit development. The two methods of control are very similar, the pliotron utilizing for control the potential difference at the terminals of a coil, the magnetron the magnetic field of the same coil; and it appears that the amount of control obtained is about the same in the two cases.

We have also made tests with magnetrons as generators of high-frequency alternating current. The

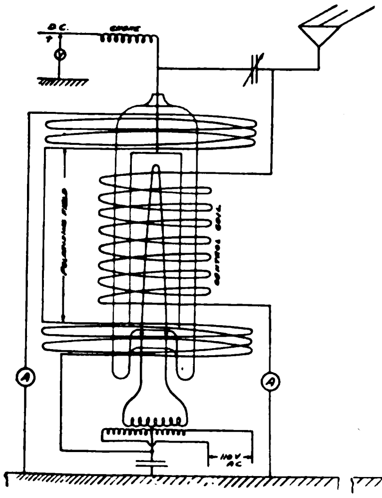


FIG. 27

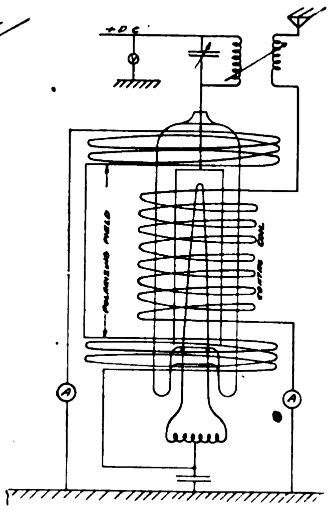


FIG. 28

tube shown in Fig. 1, which has an anode 4 in. in diameter by 12 in. long, has been operated with an output of 5 kw. of high-frequency power, and is capable, with proper development of the circuit, of 25 kw. output. The circuits used are shown in Figs. 27 and 28.

It is thus possible that the magnetron will find applications in the radio field. It has the advantage of cheap construction, and of separating the input and output circuits. Its most probable service in this field is in combination with other methods of control. The tube shown in Figs. 23-25 is by far the most efficient oscillator we have tried.

The field of radio is insignificant, however, compared with that of engineering, and it is in engineering that vacuum tubes will find their most important applications.

One of these applications is the use of magnetrons as lightning and surge arresters. The magnetron is connected in multiple with the machine to be protected, and the magnetic field is adjusted so that no current flows through the magnetron under normal conditions. If the voltage rises above normal, however, as soon as it reaches a definite predetermined excess the magnetron valve opens wide, allowing very large current to flow, but closes again as soon as the voltage falls below this same value. The time lag in the tube is nearly zero, manifold smaller than in the sphere gap, and the magnetron may find applications where this speed is important. Fig. 29 shows a simple application in which a magnetron is used to protect a high-voltage d-c. line.

I have pointed out some of the applications for which the magnetron is especially adapted. There are many other applications for which vacuum tubes

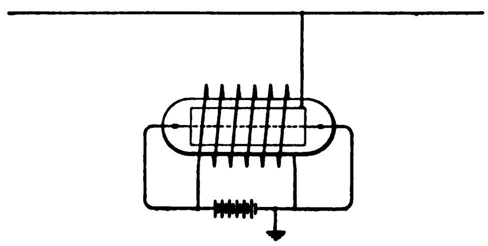


FIG. 29

are suitable, and for which one may confidently predict they will be used. Their capacity is ample. The tube shown in Fig. 1 is capable, with larger filament and water cooling, of handling hundreds of amperes at almost any voltage used in engineering. One may predict that one year will see these tubes in use as kenotron rectifiers for series arc lighting. Five years will see them in substations replacing synchronous converters. In ten years they will be on electric locomotives, either as rectifiers, allowing the use of d-c. motors, or as variable frequency alternators, taking their power from a high-tension d-c. trolley line. Twenty years will see d-c. transmission lines, fed through transformers and kenotrons, at any convenient points, by alternators of any frequency, and tapped by the same tubes acting as magnetron alternators, or some equivalent pliotron or combination vacuum-tube alternator.

The power capacity of tubes is ample for these purposes. Electron devices are not small inherently; they are only young.

Turbine Reduction Gears Versus Electric Propulsion for Ships

BY ESKIL BERG

General Electric Company

The question of whether electric or geared propulsion should be used depends entirely upon the type and operating conditions of the vessel. The Navy Department after years of comparative study, and having actual operating data on electrically propelled vessels available, has decided to equip all the larger Navy vessels with electric drive. In this type of ship, electric drive has a decided advantage, as economical cruising speed (which is so important for this type) can be obtained, the machinery can be located in the most convenient place farthest removed from disturbances from gun fire or torpedoes, plurality of generating units can be used so that damage to one or more parts will not disable the vessel, and maneuvering can be accomplished more quickly and accurately, etc.

Geared turbine drive has an advantage in fast destroyers and light cruisers. In this type of vessel, the power is generally large and the propeller speed very high—factors which make ideal gear conditions. Geared turbines can here be built very much lighter than electric drive and, as the weight of propelling machinery in this type of vessel is of utmost importance, electric drive being heavier cannot be considered.

In merchant ships each individual case must be studied, and here the questions of service, economy, reliability, weight and cost must be taken into consideration.

For fast passenger liners, electric drive has an advantage. The transmission efficiency can be made practically equal to a conservatively proportioned double-reduction gearing. It has, also, the advantage that the more efficient turbine can be built.

If two generating units are used, one unit will propel the vessel at about three-quarters speed with only slight sacrifice of economy. Noise, so objectionable in passenger vessels, is practically eliminated with electric drive.

In moderate-power twin-screw ships of about 6000 to 8000 h. p., electric drive has a decided advantage both in economy, weight and price, if one turbo-generating unit is used to drive both propellers. In case this unit, or any of its auxiliaries, should become disabled, a simple arrangement can easily be made by which the ship could be run at low speed from the auxiliary generating unit which normally drives the electrically driven auxiliaries.

On the other hand, if two generating units are used, the equipment becomes slightly less efficient, the weight and cost also go up considerably, and the comparison then becomes similar to a 3000-h. p. single-screw freighter.

Low-speed single-screw freighters, 2500–3000 h. p.: Here the geared turbine is somewhat lighter. The actual transmission efficiency of the gears is also better. However, when the losses of the reversing turbine, power taken by the oiling system, packing losses, as well as leakage of steam due to larger clearances, are taken into consideration, the transmission efficiency is practically equal to—if anything in favor of electric drive. If, however, the motor is located aft, doing away with long shafting with its expensive bearings, supports and shaft alleys, the electric drive is the lightest, cheapest and most economical, as well as the most reliable method to use. With the main auxiliaries driven electrically, the ship can by very simple arrangement be run home by power supplied from these auxiliary units, should the main propelling machinery or its auxiliaries become disabled.

In freighters of 1500 h. p. or less, geared turbines are lighter and cheaper. As the power is small, a gear can be designed which is less affected by sudden load variation or disalignment caused by springing of the hull or inaccurate workmanship.

THE modern steam turbine when considered simply as a prime mover has demonstrated its superiority in both efficiency and economy as compared with the reciprocating steam engine. The problem confronting marine engineers today is that of selecting the best methods of applying the steam turbine to ship propulsion in a way that will secure the highest over-all efficiency for both the prime mover and propeller.

Three general methods by which this is accomplished will be discussed in detail, but can be briefly outlined as follows:

(1) The turbine directly connected to the propeller shaft. This method involves a serious sacrifice in the efficiency of both turbine and propellers, as the former must be operated a speed greatly below its point of best economy and the latter must be operated at a speed greatly in excess of that which will give a maximum propeller efficiency. This compromise method of direct connection between inherently high-speed and low-speed units, despite the attractive feature of its apparent simplicity, results in such low over-all efficiency that, except in special cases, it is not now seriously considered as a feasible method by designing engineers.

(2) Interposing a gear train between turbine and propeller. This method permits both the prime mover and the propeller to operate at efficient speeds but involves the design and construction of single- or multiple-reduction gears which must withstand continuous operation under severe service conditions. It also necessitates a separate turbine element for reverse operation of the propeller.

(3) The third method, in place of the mechanical gears, interposes what might be called an electrical gear between the turbine and the propeller. In this case the turbine is designed so as to secure the highest efficiency in the operation of an electric generator, and the driving motor, which is direct connected to the propeller, is in turn designed solely for that service. All reversing is done without reversing the turbine.

Presented at the Joint Meeting of the N. Y. Section of the American Institute of Electrical Engineers and the Metropolitan Section of the American Society of Mechanical Engineers, New York, N. Y., January 28, 1921.

While the first method has practically been abandoned by marine engineers for commercial ships, the second and third methods have been applied to a considerable number of ships of various tonnage ratings and speeds, and the operating records which are now available make it possible for the marine engineers to determine which methods should be applied when the service conditions are known.

Advantages of Steam Turbine over Reciprocating Engine

When steam is used as a motive fluid, the steam turbine is by far the most economical prime mover. The turbine substitutes simple rotation for the complicated mechanical functions of a reciprocating engine.

In a turbine, an expansion ratio of 400 to 1 can be obtained, the limit of expansion being entirely governed by the temperature of the cooling water; whereas, in a reciprocating engine, the limit lies in the size of the low pressure cylinder. Marine engines generally have an expansion ratio of 15 to 1, or less. The net result is, that the turbine realizes about 25 per cent more energy out of the steam than the reciprocating engine, and can do so more efficiently.

No power station on land could today afford the use of reciprocating engines for the production of power and, with the greatly increased price of fuel, their use on shipboard is bound to become less and less.

When the turbine is considered for ship propulsion, there are a few facts about this machine which must be fully understood. These may be discussed as follows:

Turbine Speed. High-speed turbines are lighter, simpler and much more efficient than low-speed turbines.

For a given horse power, there is just one speed (rev. per min.) for which the turbines can be made most efficient. If, for any reason, this speed is reduced an inferior turbine is bound to result. The great majority of turbine ships now in operation have turbine speeds entirely too low for best economy, and the net results may, in some cases, even show an economy poorer than a reciprocating engine ship. This condition has, no doubt, retarded the introduction of turbines for the propulsion of ships.

Propellers. Propellers are limited to low speed for high efficiency. Turbines cannot, therefore, be directly connected to the propeller shaft, although it has been done with great sacrifice of economy on some very fast and powerful passenger vessels, as well as fast warships and destroyers.

The *Mauretania* is probably the best example of what can be done with this arrangement. She has 4 screws and develops about 69,000 h. p. with a propeller speed of 188 rev. per min. The turbine equipment consists of two (2) high-pressure turbines and two (2) low-pressure turbines, each connected to the propeller shaft. This really makes two (2) complete turbines in the ship, each having 34,500 h. p. In order to be able to make the best turbine possible for this horse power, the speed should have been about 1400 rev. per min. instead of 188 rev. per min. The net result is that the turbine for the big *Mauretania* has an efficiency of only 62.75 per cent, which is much lower than the Curtis turbines now being used on 2500 h. p. freighters with double reduction gearing or with electric drive. Turbines of 35,000 h. p., running at 1500 rev. per min., are now in daily use, the efficiencies of which are over 80 per cent, or 27.5 per cent better than the low-speed *Mauretania* turbine.

From this it will be seen that, in order to maintain the good economy of the high-speed turbine, and at the same time make use of an efficient low-speed propeller, some form of reduction gear must be used between the turbine and the propeller. This condition is what has brought forward the mechanical reduction gear as well as the electric drive.

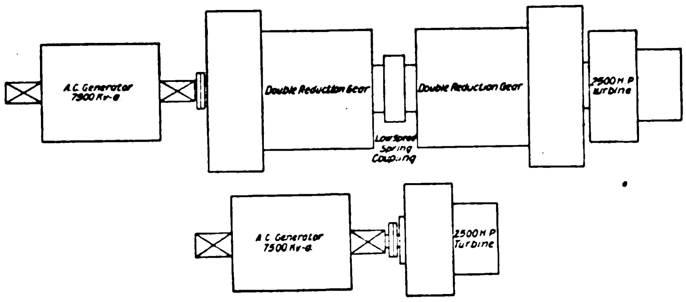


Fig. 1

Single Reduction Gears. In every case, with the exception of destroyers and light scout cruisers, the writer has found that, in order to be able to use single reduction gears, the turbine speeds have to be made too low to produce the best result, and also that a propeller speed has to be chosen which is too high for good performance. A compromise is, therefore, always necessary, and the net result is an economy less than that obtainable with either double reduction gears or electric drive. The table below gives the approximate horse powers and speeds required for the best efficiency, with turbines of the type most used for ship propulsion, and any reduction of these speeds will handicap the turbine.

H. P.	Speed		H. P.	Speed	
1000	8000	rev. per min.	10,000	2550	rev. per min.
2000	5700	"	12,000	2330	"
3000	5160	"	15,000	2090	"
4000	4030	"	18,000	1900	"
5000	3600	"	20,000	1800	"
7000	3040	"			

This table also shows that, even with double reduction, gears of the types now used give turbine speeds which are lower than those suitable for best results.

Losses in Gear Drive. These losses consist of losses in the gears themselves as well as turbine losses.

Efficiency of Gears. Most careful tests have been

made by the G. E. Company to determine the efficiency of the type of double-reduction ship gearing which it is using. These tests were made in its testing room under perfect operating conditions. The gears had perfect alignment, ran practically noiselessly, and everything was favorable to obtaining high efficiency. The tests were made by connecting two ship gears together, having the turbine on one end and a high-speed generator on the other. Fig. 1 shows the arrangement diagrammatically. After these tests had been run under varying speed and load conditions, the gears were removed and the turbine was connected directly to the same generator.

A comparison of these tests gave the gear losses of the two ship gears and, as these losses were twice that of one gear, they could be accurately measured. The result of these tests is given in Fig. 2. On this curve 1540 h. p. corresponds to what would, by present standards, be considered conservative tooth pressure

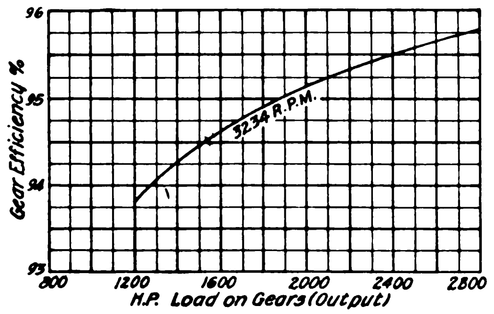


Fig. 2

for long life of the gears. The efficiency at this point is 94½ per cent.

Tests made in similar manner on single reduction gears, but of smaller capacity, indicate that for a conservative design, with such speeds as would generally be required in ship work, an efficiency of 97 per cent to 97.5 per cent may be expected. This gain in efficiency over double reduction is, however, lost in the turbine as it must be designed for lower speed.

The result of all the gear tests made shows that, low peripheral speed and high tooth pressure give the best efficiency and the efficiency falls off rather rapidly with increased speed and lower tooth pressure.

Loss in Reversing Turbine. The friction loss of the reversing turbine depends, of course, upon the design and the degree of reversing torque desired. Tests have been made in Schenectady on the reversing turbine of a 2500-h. p. ship. This reversing element gives full-load torque at stand-still, has two (2) stages and is specially proportioned to give low rotation loss.

The tests were made by driving the reversing wheels alone in a vacuum with a high-speed synchronous motor. With 28 in. vacuum and with highly superheated steam in the casing (about 300 deg. superheat) this loss amounted to 28 h. p. In actual operation one of the reversing wheels runs in contact with steam which is kept in motion by the forward turbine and which carries about 12 to 15 per cent moisture. This condition greatly increases the rotation loss, and a conservative estimate of the rotation loss of the reversing wheels during actual operation would be 44 h. p., or 1.76 per cent loss. If, for any reason, the vacuum should be impaired, this loss increases practically as the absolute back pressure and, in tests actually made, we have found that, with 20 in. vacuum and normal speed of the turbine, the buckets of the reversing wheels turn blue with heat.

Heat Variation While Reversing. In the act of reversal, work is done upon the steam before it can begin to do work, and this work all goes into superheat. This work comes from motion against the force of the steam, this motion being the result of momentum of parts and the effect of the water to keep the propeller going in its original direction. That this superheating, under some conditions, reaches a very high temperature is now well known and many turbine failures can be directly attributed to this cause.

If, for any reason, backing is done for any length of time, when an order for "forward" is received, these same heat variations occur in the main forward turbine during these great heat variations the turbine casing, as well as the moving parts, are bound to move in relation to each other and thus large clearances are required, which tend toward lower efficiency of the turbine.

Transmission Efficiency of Gears. From the above it will be seen that the efficiency of a conservatively designed, double reduction gearing is about 94½ per cent; also that the loss incident to the reversing turbine is about 1.76 per cent, making a total loss of 7.26 per cent. Besides, there is a loss in efficiency of the turbine itself due to the necessity of larger clearances and the fact that the reversing turbine makes the turbine longer, which means larger shaft and greater leakage loss between diaphragms, as well as increased packing and bearing losses. To this should be added the power taken by the various pumps required for the oiling system.

If the turbine for any reason is split up into two casings (high and low), there are additional packing losses as well as loss during transfer of steam from one turbine to the other. This latter loss is large and may amount to 2 per cent or 3 per cent.

Life of Gears. During the war several hundred geared turbine ships were built. Some were of single-reduction type with a single turbine; others had the turbine split up into two casings (high and low). The majority of ships however, in order to obtain an efficient turbine, were equipped with double reduction gearing. Here again the turbine was built either in one casing, or split up into two casings.

A few of these gears have given excellent results particularly those employed on war ships, where maximum power is only used on rare occasions. In the

merchant marine there is also quite a number of geared turbine ships giving successful operation. There has, however, been a great number of very serious gear failures. In many cases similar equipment in similar ships would give entirely different results in regard to life of the gears.

With the experience and knowledge now acquired there is no doubt that some of the early gears were entirely too small to stand the great fluctuating load which takes place due to the variation of propeller torque in heavy seaway, as well as the excessive load on the gears caused by any misalignment due to distortion of the hull in heavy seaway, which would change the load distribution of the gears.

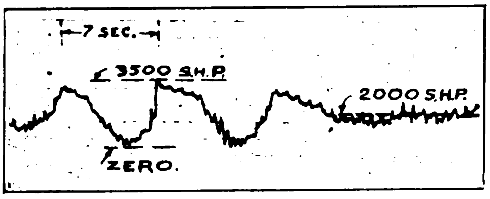


Fig. 3—Record from Torsion Spring Coupling on S. S. *Jebson* in Ballast in a Moderately Rough Sea. Average rev. per min. 78. Average shaft h. p. about 2000. Part of the smaller fluctuations shown came from an untrue collar in the instrument, otherwise record is correct.

Variation of Propeller Torque. A torsion spring coupling was applied to the S. S. *Jebsen* when running in ballast. The average horse power was 2000 and the propeller rev. per min. 78. In a moderate sea, with the ship pitching only 4 degrees, the load varied every 7 seconds from 0 to 3500 h. p. This variation of horse power no doubt is caused by the high flywheel effect of the rotating parts of the turbine and gears, which prevents the slowing down or speeding up of the propeller to follow the large load variations on the propeller while in heavy seaway.

Knowing the inertia of the turbine and the gears, a load variation, as shown in Fig. 3, would indicate that the propeller speed varied from 74 to 82 rev. per min., with a mean of 78 rev. per min. every 7 sec.

Distortion. Recently, on a 2500 h. p. gear casing which measures about 10 in. by 11 ft., a light thrust beam was pivoted and multiplying devices arranged by which any movement of the corner of the gear casing with relation to the ends of the arm could be noted. Readings were taken under different conditions of sea and wind. Under one condition of heavy quartering sea, the starboard after corner of the gear casing had an apparent movement, of which the amplitude of relative motion showed 0.05 of an inch. At times the relative motion was somewhat of a vibratory character, being affected by the tremors of the ships.

While these relative movements may, in part. have been caused by springing effect of the gear cover which supported the arm, nevertheless the movement must have affected the alignment and load distribution of the gears and may account for the large excess pressures which seem to be indicated by the performances of many ship gears.

Electric Drive

Electric transmission affords a simple and practical means of speed reduction in almost any ratio which may be desired.

Reversal. It affords means of reversal by simple change of electrical connections without changing the direction of rotation of the turbine.

Reversing Torque. Any desired reversing torque up to the full power of the turbine can be obtained without affecting the efficiency of the equipment in forward direction.

Power Measurement. Electric drive makes it possible to obtain accurate data, either by instantaneous reading or by recording instruments, of the load on the propeller shaft under various conditions of sea and wind. It also gives means by which the total horse power-hours are recorded during any given time or journey. By comparing these data with the fuel consumption a direct check can be obtained as to economy.

Noise. Electrically driven vessels are practically noiseless, whereas with gears there is always bound to be considerable noise.

Maintenance. Electrification of factories, locomotives and large rolling mills has reduced the maintenance cost to only a fraction of what it was before such electrification was made. Experience in this respect on the electrically propelled ships built in this country has also proved that the up-keep so far has been practically nil.

Economical Cruising Speeds. In warships or other vessels which need to operate economically at reduced speeds, electric drive affords means by which the ratio of speed reduction may be changed by simple electrical connections; thus making possible the economical use of the same apparatus both under high speed and reduced speed.

Interchangeability. Electric drive makes it possible to use a plurality of generating units so that damage to one or more parts will not disable the vessel.

Economy at Reduced Speed. In many of the fast passenger vessels it may be desirable to run at lower speed during certain seasons of the year. With electric drive, where two or more generating units are used, one or more of these can be shut down with all its auxiliaries and an economy can be obtained at reduced speed almost equal to that at maximum speed.

High Steam Pressure and Superheat. With electric drive, full advantage can be taken, without risk, of the increased economy afforded by high steam pressure and superheat, since the turbine itself is never reversed.

Design of Turbine. The turbine for electric transmission can be built for better efficiency. Since no reversing wheels are required, the turbine becomes shorter, which gives a smaller shaft, less packing leakage

and less weight which reduces bearing loss. Since there are no heat distortions during reversal, smaller clearances can be used. The turbine is built in one casing. Thus the packing and other losses incident to splitting the turbine up into two or more casings are avoided.

Location of Apparatus. Electric drive in many cases may afford another important advantage, namely; that the generating unit, or units, can be placed in any convenient place near the boilers, with their condensers mounted directly under the turbine, thus reducing the steam and exhaust piping to a minimum and diminishing chances of air leaks so detrimental to good vacuum condition. The propelling motors can be placed near the propellers, thus eliminating long, expensive shafting, and the bearing losses incident to the same, and shaft alleys, thus saving hold space and making cargo handling very much more convenient.

Auxiliaries. With electric drive, a great many of the main auxiliaries can advantageously be electrically driven and this affords a large saving in fuel. In case of any trouble with any of the main propelling machinery, or condensing equipment, arrangements can very easily be made by which the ship can be propelled at reduced speed from the auxiliary power circuit. This feature should be valuable for single-screw vessels.

Reliability. The simplicity and reliability of the electric motor are too well known to need further comment. It is doubtful if anything so reliable has ever before been used to drive a ship. The Navy Department, after most careful co nparative study, has adopted electric propulsion for all of our large naval vessels. The Shipping Board is, at the present time, replacing twelve 3000-h. p. geared ship equipments with electric drive. The first ship, the *Eclipse*, of about 11,900 tons, has successfully finished her trial trip and is now on her way to the East Indies. On her trip from New York to Gibraltar she beat the record of similar ships by two days (about 15 per cent) and reported everything running finely and most satisfactory.

Weight. It is very hard to give a direct comparison of weights between electric drive and geared drive as it all depends upon the type and service of vessels. For destroyers, light, high-power cruisers, or fast pleasure yachts, the geared turbine is very much lighter. In high-speed passenger vessels, the turbine and the gears themselves may be slightly lighter than electric drive but, when the steam and exhaust piping and oiling system are taken into account, the difference in weight is so very slight that it cannot be of any consequence.

The weight of the electric propelling equipment alone of the Collier *Jupiter* (7000 h. p., twin screw) is 156 tons; the weight of the geared equipment on the *Neptune*, sister ship, is 150 tons. When the piping, oiling system, etc., are added the *Jupiter* equipment is lighter.

In low-speed freighters of about 2500 or 3000 h. p., a conservative gear design of double reduction type with single-unit turbine, as built by the General Electric Company, weighs, including oiling system, about nine (9) tons less than electric drive. If, however, with electric drive, the motors are put aft, where they really belong, the saving in weight of shaft, bearing supports, shaft alleys, etc., makes the electric drive very much lighter.

As compared with reciprocating engines, the electric drive weighs only about 40 per cent of the engine.

Cost. While the electric drive may in itself be slightly more costly than geared turbine drive, the saving incident to piping, foundations, shafting, shaft alleys, oiling system, etc., makes it in many cases by far the cheaper.

Efficiency of Transmission with Electric Drive. The propelling equipment of the S. S. *Cuba* (17 knots, 3000 shaft h. p., 100 rev. per min. passenger boat) had a most complete test at the factory. The motor showed an efficiency of 95.65 per cent, including excitation, and the generator gave an efficiency of 96.3 per cent. The transmission loss is, therefore, 7.89 per cent. The cable loss is about 0.04 per cent, making a total loss of 7.93 per cent. This figure compares with gear 7.26 per cent, the difference being only 0.67 of one per cent in favor of gearing. With increasing horse power, the efficiency of the generators and motors becomes better and, in machinery designed for certain high power ships, the efficiency reaches 94 per cent.

Superheat. The introduction of high-speed turbines driving electric generators, with high degrees of superheat, has enormously reduced the cost of power for all purposes on shore. In fact, no power plant could today afford to run without superheat. On board ships, improvement in economy in the engine and boiler rooms is several times as important as in power stations, for ships must not only buy their fuel at prices prevailing in various parts of the world, but must carry it for long distances, thus displacing useful freight carrying capacity. While the use of high degrees of superheat on board ships in this country has, up to the present time, made little headway, the introduction of electric drive should greatly hasten this great advance toward fuel economy.

Performance. Following is a list of electrically propelled vessels, the machinery for which was built by the General Electric Company.

Chicago Fire Boats. Two of these boats were equipped with electric propulsion in 1908. They are twin screw boats of 500 h. p. capacity. The performance of these boats has been excellent from the start. Up to the present time no repairs to the equipment have been necessary.

Collier Jupiter. The *Jupiter* has a displacement of 20,000 tons and is a twin-screw boat. On her official 48-hr. trial, she developed 7160 h. p. and maintained a speed of 15 knots (one knot over guarantees). She has been in continuous operation since February, 1914, during which time she has seen the hardest kind of service. She holds the record in the matter of fuel economy as well as of mileage covered during this period. As to her performance and upkeep, Rear-Admiral C. W. Dyson expresses it as follows:

> It is hard to imagine any installation of machinery which could have been more satisfactory than that on board the *Jupiter*. Her repair bills are practically nil, we never receive any adverse reports or criticisms from her, and so far as appeals for navy yard assistance are concerned, we do not know that the ship is in existence. In my opinion, electric propelling machinery is on its way as the peer of all propelling machinery, and I expect to see a wide spread in its use in the near future.

New Mexico. The *New Mexico* has a displacement of 32,000 tons and belongs to our latest and largest class of battleships. She is a four-screw ship and at maximum speed develops 32,500 h. p. She has been in operation over two years, during which time there has never been trouble of any kind with the electrical equipment. During the gun trials when all the twelve 14-in. guns were fired broadside, there was not a loose wire, cable or broken insulation to be found.

The fuel economy of the *New Mexico* came up to expectations. In *Marine Engineering* of May, 1920, there was a most interesting article entitled "Two Years of Electric Propulsion on the *New Mexico*" by Commander S. M. Robinson, Fleet Engineer of the Pacific Fleet, of which the *New Mexico* is the flag ship. He compares it with the *Idaho* and *Mississippi* which are sister ships of the *New Mexico*. The *Idaho* and *Mississippi* have direct connected turbines but with geared cruising turbines (the *Idaho* having Parsons turbine, and the *Mississippi* Curtis). The *Idaho* can use her geared cruising turbines up to 17 knots and the *Mississippi* up to 15 knots.

The table below gives a comparison of the fuel economy.

At	10 knots	the *Idaho* and *Mississippi* consume about	20%	more fuel
"	13 "	" " " " " "	42.7%	" "
"	16 "	" " " " " "	47.8%	" "
"	19 "	" " " " " "	40.1%	" "
"	full power	" " " " " "	32.0%	" "

The *New Mexico* has also been awarded the highest merit in engineering for the year of any battleship.

S. S. Eclipse. The *Eclipse* is a freighter of 11,868 dead weight tons; 440 ft. long; 56 ft. beam; belonging to the United States Shipping Board. She was originally equipped with geared turbines which were removed and electric drive was substituted. She is a single-screw vessel of 3000 brake horse power, and is equipped with one (1) turbo-generator supplying power to a 3000-h. p. 100-rev. per min. induction motor. All her trials were eminently successful and she is at the present time on her maiden trip to Singapore and Java with full cargo. A cable received from Gibraltar states that she broke the record of similar ships to Gibraltar by two days. The arrangement of the auxiliary steam is very wasteful, several hundred horse power being wasted. Still, unofficial figures indicate that, although making higher speed, the fuel consumption is less per day than before.

Cuba. The *Cuba* is a passenger vessel of about 4000 tons and 3000 shaft horse power. She is equipped with one turbo generator and the propeller is driven by a 3000 shaft horse power synchronous motor, running at 100 rev. per min. As she was the first synchronous motor ship, her trials as to maneuvering and reversing were most extensive and proved most satisfactory. In fact, reversing from full speed forward to reverse was done too quickly to suit the captain and chief engineer, and changes in control were made to accomplish this reversal in a little longer time. The ship makes between 17 and 18 knots and is at the present time in regular passenger service between Jacksonville, Fla., and Havana, Cuba.

No records as to fuel consumption are as yet available.

The following is a list of electric propelling machinery now being built by the General Electric Company:

For the Navy.

3 battle-ships	*California* *Maryland* *West Virginia*	each 32,000 h. p.—total	96,000 h. p.
2 battle-ships	*Iowa* *Massachusetts* *Constitution*	" 60,000 h. p.— "	120,000 h. p.
4 battle cruisers	*United States* *Saratoga* *Lexington*	" 180,000 h. p.— "	720,000 h. p.
		Total—	936,000 h. p.

For Merchant Marine.

11—3000-h. p. freighters similar to the *Eclipse*	33,000 h. p.
4—2600-h. p. coast guard cutters, synchronous motor	10,400 h. p.
1—3000-h. p. United Fruit Company	3,000 h. p.
Total	46,400 h. p

MANUFACTURE OF ELECTRICAL EQUIPMENT IN AUSTRALIA

With the growing interest in the use of electrical equipment and appliances in Australia, involving many new schemes for the employment of electric power in place of coal for motive and railway uses, new plants for the manufacture of electrical goods are being erected, writes Vice Counsul Ray Fox from Melbourne. He also states that the Victorian Railway Commission, which operates the Government-owned railroads of the State, is gradually electrifying the railway system of Melbourne and surrounding suburbs the entire system being scheduled for completion by 1923 and calling for large orders of electrical equipment.—*Commerce Reports.*

The College Trained Engineer

Suggestions for Improvement

BY C. EDWARD MAGNUSSON

Chairman, Educational Committee, A. I. E. E.

IN the annual report (1921) of the Educational Committee to the Board of Directors reference is made to a circular letter which was sent to a hundred prominent electrical engineers, requesting constructive suggestions for improvement in the training of engineering students in our technical schools and colleges. Three questions or topics were submitted:

1. State what is the basic thought or philosophy that should be impressed on the student which will serve him best as guide in his future work.
2. Suggest a problem or problems, a better knowledge of which would help the student later to take up work in your own field.
3. Give a suggestion or two that would aid in making college training of embryo engineers more effective.

A study of the sixty-eight replies received reveals a remarkable unity of opinion. Several of the suggestions are found in a majority of the letters and many of the writers apparently hold identical views as to what is essential in the training of engineers. A valuable contribution towards a better understanding of fundamental principles in engineering education is made by Mr. B. G. Lamme, whose letter is incorporated as an important part of this report.

FIRST QUESTION

The majority of the replies to the first question may be summarized in one word—*service*. The young engineer should be governed by an earnest desire to accomplish something useful and worthwhile; to become a constructive force in the community; to be considerate of the opinions of others, and to cooperate cheerfully and unselfishly. Of the other suggestions may be mentioned "a better appreciation of the economics of engineering," "the value of health," "the importance of scientific knowledge and research," "never to cease being a student," etc.

"That service is the key-note of life. Service is based on work and the philosophy applies to students as well as to those with whom the student comes in contact."—R. W. E. MOORE.

"A definite choice of his engineering environment with a selection of the essential feature he desires to follow. After selection of this feature an untiring effort in preparation to become a master of it should govern his procedure, with the predominant thought always in mind *to give service*........An engineer should give service at the beginning of his life but I hold that a greater individual happiness accrues to him who progressively increases service as his life is lived. In other words, there is greater wealth and greater happiness in an accumulation of service than money. Therefore, integrating all I have said regarding (1) I would say the philosophy that should be impressed upon the young engineer is that he should give service." —W. S. MURRAY.

"That *service*, in the broadest sense, is the best motive in life, and that success in rendering it should be every man's controlling principle, both in selection of a vocation and in pursuit of it."—FRANK F. FOWLE.

"The awakening of the imagination to a conception of the usefulness and scope of knowledge. To seek to know and remember the reason for a fact and not simply the fact itself."—W. L. R. EMMET.

"I can only give you from my own personal creed what I believe to be the biggest idea that any engineer can get, and that is service. To get this across to the undergraduate I believe that you should make him feel that the world is not equipped with machinery and simply waiting to carry out his ideas but that the world has a great many problems to solve and is waiting for him to help in the solving. Perhaps the appreciation of the value of a spirit of service grows with increasing years better than any other way, but I have a feeling that it can be communicated to younger men if gone about in the right manner."—A. M. DUDLEY.

"While a knowledge of engineering fundamentals is quite necessary, the supreme importance of applying just plain common sense in all problems should constantly be kept in mind. This common sense should be applied in all other affairs of life as well as in engineering and the student should learn the value of mixing with his fellows and taking a live interest and active part in affairs of citizenship."—R. F. SCHUCHARDT.

"Keep your mind always open. Never accept any working hypothesis as an indisputable or immutable law......Above all things, however, make the college really democratic and drill into the student's heads that all they obtain at college is a training in how to think and a grounding in the fundamental principles so that they are ready to start life's work. The college student who starts life's work with an idea that because he has been to a certain college of high reputation he is better than other young men who have not been to college, has a serious handicap and it takes him some years to jockey for a fresh start."—TALIAFERRO MILTON.

"By *attitude* is meant much. It combines cheerfulness, cooperation, self-helpfulness, determination and consideration for others, in a happy balanced combina-

tion which allows—the more or less—otherwise untrained to fit in, be liked, progress and get results where another of much superior understanding and training, but without attitude, completely fails. Attitude absolutely ranks ability in every normal competition. There may be lone instances where ability might excel, but never in 'team work' which in modern industry and society is almost always the invariable rule. I would much prefer that my boys should have the proper attitude and merely very ordinary ability than wonderful ability and poor attitude. Attitude is a phase of the 'make-up' demanding initial mental endowment. Fortunately, therefore, attitude can be acquired, while the capacity to demonstrate ability seems to lie with each individual."

"Obviously *health* is essential, and proper conservation and regard for the physical should be impressively and constructively emphasized. Young men are often careless and make commitments against their 'health credit' which have to be taken up later, when 'exchange' may be very unfavorable."—K. C. Randall.

"With regard to a basic philosophy, I think a college man above everything else must be taught to be honest and to have consideration for others' opinions and ideas as his progress will depend largely on his ability to get along with others. He must learn to build up and construct, helping others rather than criticise and tear down and get his reward from the cooperative effort and confidence others place in him."—G. W. Ashe.

"Instill in the minds of the students their individual or personal responsibility to their profession as engineers and citizens. Proved initiative and ability are recognized above a diploma, but a diploma gives a man a head start."—O. D. Higgins.

"At the risk of accusation of being a gross utilitarian I would state that the criterion of all engineering work in the industrial world today is 'Will it pay?' This measuring rule is a flexible one and may involve a prophetic insight of the future economic conditions; it may further involve an idealistic conception of the value of beauty of form and arrangement; or again it may be a discernment of the value of social and welfare relations in the economic life of the community. In the last analysis, however, engineering work must pay or it is futile."—L. T. Merwin.

"That greater emphasis should be placed on what may be called the economics of engineering. That is, generally speaking, engineering is only a means to an end and not the end in itself which usually has a place in the economic structure of the locality or corporate system. Its value will be measured by how efficiently it articulates with the remainder of the project and its all around economy as a part of the whole."—S. D. Sprong.

"The basic thought or philosophy which should be impressed upon the student is the value of scientific knowledge and research in our modern industrial development and the important position which the Engineer occupies in conserving and developing our natural resources for the use and advantage of mankind in a way to improve living conditions and increase the wealth of the peoples."—Wm. S. Monroe.

"Do everything possible to give the student vision, cautioning him, if you will, against the serious results of confining himself solely to a technical field of work. To be well versed technically is necessary, but he must read good literature and keep abreast of the world's affairs in matters other than technical in order to have a broader vision, so that his imagination will be developed and that he may know the problems other than in his own particular field, and from these problems may gain thoughts that will be of great benefit to him."—S. J. Lisberger.

"If some one thing is needed now to help students, it would seem to be that they should know more of the truth about themselves, particularly as to their location in the picture and as to its perspective. It is very doubtful if they generally appreciate that life is a continuous educational process and that nothing definitely separates the particular part of life that they spend in college from what went before or what is to follow. It is simply a period when it is easiest to learn certain kinds of things and coming as it does when students have little earning power, it is a very convenient time to allow them to concentrate on the accumulation of knowledge, in much the same way that kindergartens are found to be convenient for younger students. That part of their educations which they use in their professions could perhaps be obtained elsewhere and at some other period, but not so easily and not so efficiently, and that is the impelling motive for colleges. That part of a student's education which is received in college is terminated by economic reasons and not by the capacity of the student to learn or of the college to teach."—E. H. Bangs.

"Reliability. This includes probity of course. But it also includes accuracy and initiative."—
Ralph D. Mershon.

"In the main we are rather of the opinion that it would be preferable, in the engineering courses, to devote more effort to the teaching of fundamentals, such as physics, chemistry, mathematics and devote less time to the specific applications through the various branches of engineering. Also we would suggest that time be devoted during the engineering course for the consideration of some of the more broadening subjects, such, for example, as English—oral and written—history, economics, philosophy, finances, business, etc."—W. M. Skiff.

Second Question

The purpose of the second question seems to have been misunderstood and was in most cases left unanswered. The purpose of the question was to gain a goodly number of new specific problems with quanti-

tative data in accord with present day practise and of such a nature as to hold the interest of the student and give him a better appreciation of the principles involved. The problems suggested are, however, stated in such general terms that little of value is gained. Some of the suggested problems are: "The elimination of waste and the reduction of cost of operation;" "analyze the heat losses and efficiency from coal pile to switchboard in a central station;" "problem of inductive interference between power lines and communication lines;" "the production of power for the joint use of utilities, railroads and industries that will give a maximum of reliability with minimum investment and minimum operating cost;" "the economic comparison of generating, transmitting and distributing power systems as between two frequencies—say 60 and 25 cycles—involving the effects of design on cost of machinery, materials and equipment, as well as the consequence of these costs in their relation to rates and the returns due to capital;" "the problem of high potential transmission and distribution of electric energy on underground systems;" "studies incident to the advisability of developing water or steam power as the load increases;" etc. To be of service these and similar problems require comprehensive data which unfortunately are seldom available for students and instructors in technical schools.

Third Question

The question invites answers of a wide range and it is therefore significant that a majority of the replies place special emphasis on the importance of a better understanding of fundamental principles, the ability to think logically and the need for training in how to approach and solve new problems. The graduate's store of information is discounted, and to give the old type of manual training in the college is considered as largely a waste of time. The need of better training in English, mathematics and business principles is emphasized in a large percentage of the replies.

"Development of the power to think is more important than the accumulation of information, no matter how great in amount. Also that which contributes to the development and accentuation of personality through discipline and culture, sees a man further than that which contributes to the equipment of the specialist. In every profession, it is the all around men that are at the top—the men who are interested in and know other specialties besides their own."—Gano Dunn.

"In my opinion, the crime of most of the colleges today is that they do not teach their students to think. They try to cram too many concrete facts into their heads. It really doesn't matter very much whether a student learns much of a concrete nature in college provided he learns to think.

"The great majority of the time should be spent in the fundamentals. There is entirely too much time wasted in most of our technical colleges on shop practise, teaching students how to do a poor blacksmith job, how to file a flat surface, etc. The few short years in college, in my opinion, can be much better spent by drilling in the fundamental principles."—Taliaferro Milton.

"My conclusions are that the greater the concentration and thoroughness with which the embryo engineers are trained in the fundamentals and their applications, the more self-reliant they will be made for practical life. I wish it to be understood that I do not aim to make engineers theorists, but I wish to instill in them broad and sound theory at the time and place when it can be done most efficiently. My idea is that a broad knowledge of the fundamentals of all physical sciences is the most liberal education with which a future engineer may be endowed."—Philip Torchio.

"Ground them thoroughly in the fundamentals of physics and mathematics; both to be taught by engineers and not by physicists and mathematicians."—A. H. Babcock.

"More time should be spent in a very thorough grounding and understanding of the fundamentals, and less time on specialties, details, the professor's hobbies, highly advanced theoretical studies, non-essentials like Latin, Greek, literature, history, etc. A sound foundation will serve for many different superstructures with their different details, while the best of superstructure will fall if the foundation is not sound. These fundamentals will differ for different branches of engineering, but many of them overlap."—Carl Hering.

"In college I would suggest furthering the idea of thinking for himself; of seeking a logical method of approach to the problem rather than seeking an answer to the problem."—"Endeavor to develop initiative. Many good men, well educated, technically trained, and fully competent to do good work have no initiative, and as a result they become merely plodders. If initiative can be developed, and if students have the training and the personality, one of the most important factors in their work is assured."—"Clear thinking may be developed before the student enters college. Clear thinking should be impressed upon the pupil, and next impress upon him to study English, that he may express his thoughts clearly and definitely."—S. J. Lisberger.

"I feel that in the actual teaching the professors and instructors confine their activities entirely too closely to text-book matter. The fundamental principles should be taught from those text-books but I feel that problems should be given that require simple reasoning in addition to the particular laws then under discussion, as the number of college students capable of properly analyzing the problem is almost zero, and the number of graduates showing any analytical turn of mind is very small. This means that all college training should be along lines that tend to make the student's mind a reasoning mind rather than one depending on memory alone."—N. E. Funk.

"The whole field of engineering, and even now of commerce and business itself, demands analytical ability of the highest order. Therefore the capacity to analyze an unknown problem, first recognizing all the elements or variables which are present in it, and then to progress step by step in considering each factor and its bearing on the objective or result sought, is today a prime requirement for personal success in engineering and industry."—FRANK F. FOWLE.

"Do not try to turn out engineers; try to turn out men well grounded in the fundamentals of engineering. Work for quality of output, not quantity. If the colleges and universities spent less on equipment and more on maintaining the quality and numbers of their instructional forces they would achieve better results than at present."—RALPH MERSHON.

"First, there is a need for more professors who are practical engineers, who have gotten out and rubbed shoulders with the world, and who are capable of doing the job they are trying to teach their students to perform.

"Second, in order to secure practical teachers it will be necessary to compete from a monetary standpoint with the industries, and this means that we have to pay attractive salaries in the teaching profession.

"Third, there should be the closest cooperation between Industry and the Institutions of Learning, and if necessary, Industry should assist in liberally endowing them in order to make the fullest use of their facilities for research work and the development of new fields of progress. This alliance of Science and Industry brought Germany to the very pinnacle of commercial success just prior to the war.

"Fourth, no engineering course should be considered complete without requiring the student to do one year's work in some Manufacturing Establishment, or in some branch of practical engineering work allied with his own course."

It is of the utmost importance to include a limited amount of business training and legal training in the engineering curriculum. Engineers, as a class, are deficient in knowledge of these subjects.

"Above all, college spirit should tend toward democracy and not to exclusiveness. More than one college graduate has prejudiced employers toward his kind by consciously or unconsciously cultivating a slight air of exclusiveness."—H. C. HEATON.

"Ground them thoroughly in the English language,; a lack of command of which in writing and speaking is the greatest single defect in the college training of most engineers. It is not enough for an engineer to be skilled; he must make his skill prevail, and the power and culture that comes from familiarity with English are tremendous forces in the success of an engineer." —GANO DUNN.

"I am profoundly impressed with the fact that the engineering student fails generally in his grasp of the English language and in his ability to put over in a terse, concise and convincing manner the scientific and analytical problems he has in mind. This inability often leads to failure in attaining the success in life that otherwise would be possible. This ability is not acquired merely by English courses in engineering curricula, but rather by analytical practise on the part of the student himself, questioning himself as to whether he would understand the message were he the other man for whom the message is designed. It is said that Abraham Lincoln became the master mind in this regard only after long and patient practise as each instance arose in his experience."—ROBERT SIBLEY.

"A better knowledge of accounting and the ability to read a balance sheet as well as a blue print." —H. L. WALLAU.

"As far as our own work is concerned, the engineers should have a better general knowledge of business, *i. e.*, banking, the laws pertaining to contracts, accounting, and all of the many aspects of business, of which the average trained college engineer knows little or nothing."—F. C. BATES.

"During the year preceding that in which the student must select his particular branch of engineering, he ought to be given a course of lectures describing what each of the different branches of engineering comprises, that is, what kind of work he would have to do, what studies he would have to take up, what the probable field for employment is, what the possible field of development is, etc. This should embrace not only the few general branches of engineering, like electrical, mechanical, civil, mining, chemistry, architecture, etc., but should also include the subdivisions; in electrical engineering for instance, such subdivisions as the generation and distributions of power, design and construction of machinery, telegraphy and telephony, furnaces, electrochemistry, teaching, salesmanship, administration, etc. At the end of such a course the student is better able to make a correct choice, and his teacher is better able to advise him, and to sort out the wheat from the chaff. A student will always do best in that branch in which he is most interested, but he often fails to make the correct choice because at the time of making it he has too little knowledge of the kind of work and study required in the various branches."—CARL HERING.

"The college professor should keep abreast with the development of the art, first, to use live material in the illustrations not with the intent of giving actual designs, but to avoid imperfections in the theory of older designs; and second, to employ constants and experimental data up-to-date rather than older data. Either set of data would serve to explain the theory, but the students are more inspired if they know that the data comprise the last word of the art. The student should compile his own engineering notes and tables for all subjects he happens to analyze; for instance, an electrical engineering student should have tables of magnetic characteristics of electrical and

silicon iron, conductivity of copper, aluminum, iron, etc., standard tables of wires and cables electrochemical constants for all metals, thermal resistivity and electric resistivity of different insulating materials, etc."—PHILIP TORCHIO.

Mr. Lamme's letter. Special attention is called to the excellent discussion of engineering education by Mr. B. G. Lamme. Much progress would be made if all members of the teaching staffs in engineering colleges and technical schools realized that "a boy goes to college for the purpose of learning to use his head, not merely to fill it."

"In reply to your letter of February 24th, asking about improving college trained engineers, I can give some of my opinions, based upon my experience with college trained men.

"In the first place, as I think I have mentioned to you before, I find that the vast majority of technical graduates from our schools have no real grasp of fundamental principles. These principles may have been taught to them, but have gone over their heads, or they have not realized that these were fundamental. The principal reason for this lack of realization, I think, lies in the fact that the students are not trained in the use of such principles. Possibly many of them would not have the grasp even if they were trained in the *use* of fundamentals, but the general indications that I have found are that they have never been drilled in the use of the fundamental principles. I can cite several instances in my own experience which may serve to illustrate the point which I have in mind.

"In my own work in college, where I took up a course in mechanical engineering, the professor at the head of the department, S. W. Robinson, had a tremendous reputation, among the boys, as a man who knew practically everything. In other words, the general feeling was, that he was a 'wizard' in engineering matters. Naturally, hearing such things, I at first held the same opinon. However, as I got to know him better (and eventually I was very close to him in engineering matters), I acquired an entirely new opinon of him. To my surprise, I found that there were a vast number of subjects about which he apparently knew little or nothing, but, nevertheless, on such subjects he could reach conclusions quickly and reliably. For example, in endeavoring to find the source of this ability, and also how he 'got at' things, I devised, from time to time, a number of special problems, which I 'sprang' on him on suitable occasions, usually in private. On such problems I had done considerable work and had encountered some difficulty which was the occasion for presenting the matter to him. I found that in practically all cases, when I first presented such a problem to him, he knew practically no more about the subject than I did, or even possibly less, but that almost invariably, after a little study, he could solve the difficulty for me and explain it to me clearly. In getting at how he did it, I came to the realization that he simply relied upon a few fundamental principles and that he brought these to bear directly on the solution of the problems, I put up to him. In many cases I had also gone over these same fundamental principles, but had no realization to what extent they could serve as tools for handling difficult work. Gradually, in watching Professor Robinson's work, I came to the knowledge that his real strength did not come from any broad general fund of information, but rather from the fact that he had apparently a limited amount of information of a sort from which he could construct almost anything he wanted. This gave me an entirely new idea of the meaning of education. With him it was a case of having a few general-purpose tools, which he could use in all manner of ways to construct a desired result; whereas, compared with him, many so-called educated men had a vast collection of tools practically none of which they knew how to use.

"This leads to another point which I want to bring out, namely, that a very large percentage of engineering students in colleges do not realize that the mathematics, which they study, is simply a tool to be used in getting results. The study of mathematics with them is simply mathematics, and not a means to an end. It is as if one would show the students some very fine instruments or tools and explain to them the construction of such tools, their fine workmanship, etc., but would never teach them how to use the tools. It is the use of mathematics that is important. Moreover, for a vast percentage of engineering work in general, it is not the difficult mathematics that is required. Algebra, geometry and trigonometry can probably take care of 99 per cent of the high grade engineering work, but unfortunately, only a very few of the students can really handle algebra and trigonometry in particular. The fault here apparently lies with their fundamental training. The knowledge of mathematics is cumulative. In other words, each part is built up on the preceding part. If the foundation is worthless, then the upper structure is of little value, no matter how much care has been taken in it. Algebra and trigonometry should be drilled thoroughly into the lower class students until they have a handy working knowledge of them and can use them in all kinds of problems. In other words, these should become almost a form of technical language. With such a foundation the student can tackle more advanced mathematics, and advanced studies requiring mathematics with greater confidence and with a grasp of principles, as he goes along, which continually prepares him for still more difficult work. But if, the foundation is bad, then the further he goes the worse he gets.

"What I want to lead up to, is that this foundation is built up mostly in the high schools and is strengthened but little in the early years in college, and, in many cases, is an utterly worthless one. In fact, if you would question one hundred engineering students in the

freshman class in any college, I think you will find that an extremely small percentage of these have ever used algebra, geometry or trigonometry outside of class work or the book lessons. Among the hundreds of selected college men, whom we have brought to the Westinghouse Company, I have found a very large percentage who give a negative answer to the above question, as to the use of their high school mathematics outside of class work. This is almost inconceivable. In my own case (I took up algebra at thirteen) I found, shortly after beginning the study that a number of the puzzling problems in higher arithmetic could be solved quite readily by the use of algebra. I also found that some of the problems in geometry which were rather complex and difficult to explain were almost axiomatic with algebraic treatment. Occasionally I find young college graduates who have had similar experiences.

"In view of the above statements, I would say that every engineering student, during his freshman year at least, should be given a most thorough training in the more elementary mathematics, and be made to use his mathematics by means of a great variety of problems, these problems constituting the bulk of the work. Those who show a total inapitude for such work could be weeded out from the engineering classes, for if they cannot do any of the elementary mathematics they have no business to tackle the higher work. When I speak of 'elementary' mathematics, I mean what the word says. I have talked with a number of college professors on this subject and quite a number of them said that they do just about what I call attention to, that is, they give their freshman a thorough training in algebra and trigonometry. But, upon questioning them further, I have found that in many cases, instead of taking up the elementary mathematics, they have attempted to teach very advanced algebra, very advanced trigonometry, etc., which the ordinary high school graduate is totally unprepared to undertake properly. In other words, they have undertaken to build on top of the existing inferior foundation instead of rebuilding the foundation itself.

"I consider this lack of fundamental mathematical training as being one of the great evils in the engineering training in America today. How can a student have a thorough grasp of fundamental principles, unless he has sufficient mathematical knowledge to do so? For many engineering principles are physically of a mathematical nature, that is, they involve quantitative conceptions. I do not mean to give the impression that mathematics consists of mathematical formulas, for some of the very highest mathematical conceptions may simply be physical conceptions, or visualized laws or relations. Some men have very strong physical conceptions and yet are not skilled in the use of mathematical formulas. Nevertheless, if one studies such men carefully, he will find, in many cases, that their physical conceptions are really a form of mathematics, which may exhibit itself in the shape of sketches or diagrams and in various other ways, which do not appear offhand to be mathematical. The physical conception, or the visualization of a fact or principle, is of immense value in engineering work, and this is something in which the student can be trained to a considerable extent, if he has the proper foundation for it.

"A very broad-spread idea, which should be combatted, is that the boy takes a college course for the purpose of collecting information. This idea is not only a mistake but is a very harmful mistake. A boy goes to college for the purpose of learning to use his head, not merely to fill it. Much of the college training today is in the nature of a filler, and much of the filler is worthless in the way of future advantage. If the boy is to be an engineer, presumably he will want to lead in something and his future work may consist largely of things which do not yet exist. Much that he acquires at school is simply the story of what is already done, that is, it covers what is already a story of the past. The value of this past work lies mostly in the principles upon which it is based, and these principles are very liable to be carried into the future. Therefore, if the college boy can be trained to set aside the vast mass of facts and results of the past, and simply recognize a few fundamentals upon which these are based, he will be fairly well equipped for his future work.

"As an indication of how little we care for the student's knowledge as a whole, I may say that in reviewing the selected college graduates for our work here, we ask them almost nothing about their work in general. We simply endeavor to find out their aptitudes, characteristics, analytical abilities, use of mathematics and how well they can use their heads. The showing, even among these selected men, is desperately poor. In fact, I am sometimes inclined to think the case is hopeless. Perhaps the colleges are not to blame for this situation,—in some cases we are sure they are not. However, if the engineering colleges would do no more than to materially improve the elementary mathematical capabilities of the students whom they turn out, they would be doing something worth while, for with this improved training, many of the college men would apply mathematics to their more advanced studies, thus resulting in greater improvement all along the line. Training the boy to use elementary mathematics skillfully, so that he can apply this knowledge, through his own initiative, to many problems outside the class-roon, means training him to think for himself; and if he thinks for himself logically, and of his own initiative, he then has the best that a college education can give."—B. G. LAMME.

To give contrast, and to some extent historical background, to the ideas expressed above, the following letter is included, as it represents the old view of engineering education, giving an excellent summary

of the qualifications the young graduate was expected to possess and the mass of information that he was supposed to acquire during four short years in college.

"Your letter of February 23rd has received considerable thought before making reply, since the inquiries you make cover very serious phases of engineering education as well as its later application in engineering practise.

"In answering the questions which you propounded, I find it necessary to confine myself to such thoughts as I may have as directly connected with the business in which I am engaged,—*viz.*, electrical engineering in a public utility corporation.

"For this specific line of work, it is suggested that the following phases of education would contribute largely to the success of an electrical engineer.

1. A thorough grounding in the theory, design and application of electrical apparatus to commercial practise.
2. A thorough grounding in mechanical engineering.
3. A reasonably thorough knowledge of chemistry in its elementary forms.
4. A thorough knowledge of steam engineering.
5. A thorough knowledge of hydraulic engineering.
6. A thorough knowledge of mathematics and modern accounting systems.
7. A knowledge of corporation law sufficient to enable one to intelligently deal with land titles as involved in rights of way, settlement of property and personal damages as incurred in daily operations, and a full understanding of the grounds upon which decisions of public utility commissions are based in settling rate questions.
8. A thorough knowledge of the underlying principles which are fundamental in the development of rate schedules.
9. A careful development of personality such as will enable a student to handle men successfully in actual business.
10. Last but not least a full and complete knowledge of the value of money invested in business and the proper relations which must be maintained in successful business between investment, fixed charges, operating expenses, and the miscellaneous other factors such as replacement charges, reserves, etc., which go to make up the complete operations of any successful business.

"In making the above suggestions, I appreciate that they cover a very wide field, but not a wider field than is covered in the various courses of studies now pursued in our higher grade colleges.

"Trusting that this review of desired accomplishments in our coming engineers may be of interest to you, I remain," etc.—L. L. ELDEN.

It should be noted that only a few letters in favor of the old view were received while a large majority of the replies offer suggestions that are in full accord with Mr. Lamme's concept of what is essential in engineering education.

RADIO FOR SIGNAL AND DIRECTION FINDER SYSTEM DEMONSTRATED

The Bureau of Standards, in cooperation with the Bureau of Lighthouses of the Department of Commerce, has developed a system of radio direction finding, by means of which the navigator of a ship can determine his position in a few minuted, using instruments under his own control. Such a device is particularly useful in time of fog or thick weather.

The Department of Commerce system of, radio direction finding consists of two or more radio transmitting stations in fixed locations, either on shore or on moored light vessels, and a device called the radio direction finder or "radio compass" located on board ship. The transmitting stations are of one of the types usually employed for radio communication, but are designed to operate automatically. The radio direction finder, as now developed by the Bureau of Standards for use on board ship, consists of about ten turns of insulated copper wire wound upon a rotatable wooden frame about four feet square. This coil is mounted directly over and is operated from within the pilot house. When the plane of the coil is parallel to the direction from which a radio signal emanates, the intensity of the signal received will be a maximum. As the coil is revolved, the intensity of the signal diminishes until a minimum is reached when the plane of the coil comes to a position at right angles to the line of the direction from which the signal emanates.

The Bureau of Standards has installed on the Lighthouse Tender *Tulip* a radio compass of improved design, and radio transmitting stations for fog signaling service, which operate automatically, at the approaches to New York Harbor, on Ambrose Channel Light Vessel, Fire Island Light Vessel, and at Sea Girt Light Station, N. J. These three transmitting stations have been in regular commission since May 1, 1921, and are the first fog-signal stations of this kind established in this country.

A demonstration was held on June 27 and June 28 at New York, at which the three stations mentioned transmitted to the *Tulip*. Interested persons made a trip on the *Tulip* beyond Ambrose Channel Light Vessel and every one present had an opportunity to work the radio compass and take bearings. A number of bearings was taken by radio while in sight of Ambrose Channel Light Vessel, and the average error of the bearings was 1½ degrees, with a maximum error of 3 degrees. An account of the demonstration is published in the *Lighthouse Service Bulletin* for July 1, 1921.

Electricity Applied to Ship Auxiliaries

BY H. L. HIBBARD

Marine Dept., Cutler-Hammer Mfg. Co., New York, N. Y.

SINCE the first installations of electric plants on the steamship *Columbia* in 1879, consisting of two Edison bipolar dynamos with capacity of sixty 10-candle power lamps each, and the first installation in the Navy on the *U. S. S. Trenton* in 1883 consisting of one Edison bipolar generator at a rated capacity of 115 60-candle power lamps and belt driven from an Armington and Sims engine; there has been great progress during these forty years in the use of electricity aboard ship. This is particularly true when we consider naval vessels where practically every moving element now receives its motion from an electric motor, but in the adoption of this motive power on vessels of the merchant marine, progress has been exceedingly slow as measured by land standards.

Even in the Navy after the Trenton's installation, although a few early lighting installations were effected and several miscellaneous experimental power installations on auxiliaries, no distinct progress was made until 1898 to 1900, when the Battleships *Kearsage and Kentucky* were constructed with electric plants of seven 50-kw. engine-driven generators and with the major portion of the auxiliaries electrically operated. Since 1900 the use of electricity in the Navy has progressed very rapidly until, as we have stated, at the present time nearly all power applications are electrical, including electrical propulsion for capital ships.

In the merchant marine field comparatively little progress was made in this country in the use of electricity after the first installation on the *Columbia*, until about the beginning of the World War in 1914, although we appreciate that small electric lighting plants had come into general use, and in a few instances electricity had been used for power applications on merchant vessels.

In 1914 the writer presented a paper before the A. I. E. E. on "Electricity the Future Power for Steering Vessels," in which he predicted from the experience then had in the Navy, that electricity would be, in the future, generally used as the power for the steering of vessels.

In a paper presented before the Naval Architects' and Marine Engineers' Society in 1917, outlining the progress which had been made in the use of electricity in the merchant marine, we expressed the belief that the time was rapidly approaching, if not already here, when the results as then obtained would justify the construction generally of vessels electrically equipped in all or many of their power applications.

Growth and Adoption

The advent of the fuel oil engine-driven ship has marked a great stepping stone in the adoption of electric power, particularly for auxiliary purposes. The first notable instance of this kind was the vessel *Christian X* constructed by the Burmeister and Wain Co. of Copenhagen, and its first voyage to this country in about 1913 or 1914 created marked attention. Since that time it is understood that 70 or more vessels of this type have been constructed or projected by that company.

In 1916 and 1917 a number of merchant vessels was built in this country including tankers and cargo vessels employing electrical auxiliaries, among others being the tanker *La Brea* with electrically operated pumps, and the tanker *Solitaire* completed last year by the Texas Co. having oil engine drive and electrical auxiliaries throughout, including electric heating. Other instances were a number of tank vessels constructed by the Pennsylvania Shipbuilding Co., propelled by geared steam turbines and having electrical auxiliaries operated by a-c. motors. At the present time there are quite a number of oil engine-driven cargo vessels with electrical auxiliaries, and others with electric drive and electrical auxiliaries, being constructed and projected in this country, and in the opinion of certain editorial writers, the outlook was never more favorable in this country, particularly for construction of oil engine-driven vessels, than at the present time. Motorships are now under construction for the American-Hawaiian S. S. Co., the U. S. Shipping Board, the Standard Oil Co., the Alaskan S. S. Co. and the Submarine Boat Corporation, and quite a number more are under contemplation for this year.

Rapid strides are being made by European countries in the adoption of the use of electricity on their merchant vessels, particularly of the motorship type, and England, as well as Scandinavian countries, is now constructing many vessels of this type. One of the most recent examples was the maiden voyage of the motorship *La Paz* to New York which was constructed by Harland and Wolf of Glasgow, which company is also constructing five additional motorships for the same line. A visit to the *La Paz* showed numerous interesting features in connection with her electrical equipments.

Generating Plant and Systems of Distribution

In the selection of the generating plant for the electrically operated vessel, considerable thought is necessary as to the number and size of the units to be installed. A number for instance, of the Burmeister and Wain vessels have three 60-kw. machines, 230-volt; the English vessel *La Paz* has three 100-kw., 230-volt; the tanker *Solitaire* has three 45-kw. and one 10-kw., 230-volt; the *Cubore* is provided with three 100-kw., 250-volt sets. The aim is in general to provide an equipment which is sufficiently flexible to permit of

Presented at the Joint Meeting of the N. Y. Section of the American Institute of Electrical Engineers and the Metropolitan Section of the American Society of Mechanical Engineers, New York, N. Y., January 28, 1921.

the operating of all auxiliaries and lights with one machine when cruising and to operate the vessels while handling cargo in port with two machines, or under possibly extreme emergency conditions three machines, one machine being however in practically all cases considered as a spare. Much division of opinion exists however, as to the wisdom of going to as many as three units, some claiming a preference for two units of larger size.

These installations have in general been two-wire d-c. systems, and such vessels as the *La Paz* and *Solitaire* have been furnished with lights at 230 volts. Generally satisfactory results are reported from the *Solitaire* for lamps of this high voltage with the exception of the small instrument lamps which are frequently broken. The officers of the *La Paz* reported frequent breakage and rather unsatisfactory results. A practise which has

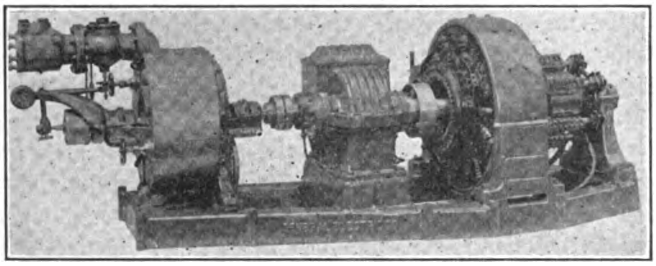


Fig. 1—Small Steam Turbine Geared to D-C. Generator, 100-Kw. Capacity, Suitable For Furnishing Power for Electric Auxiliaries on a Steamship

been followed by the Burmeister and Wain Co. and has found general favor amongst engineers in this country also, is the use of a small motor-generator set for reducing the 230 volts of the generators to 110 or 115 volts for the lamps, and providing this small machine with sufficient flywheel effect also to smooth out any pulsations from the auxiliary oil engines and fluctuation of voltage due to sudden changes of loads on the generators. The 110-volt lamps are furthermore in addition to being mechanically stronger, more universally obtainable.

Direct Current versus Alternating. A few years ago a considerable controversy existed between engineers as to the advisability of the use of alternating and direct current on shipboard, and as previously outlined in 1916 to 1917 a number of vessels was constructed in this country, including vessels of the cargo and tanker type, which had a-c. equipment. It was contended by some at that time that direct current was impracticable, particularly for tanker vessels, owing to the danger of igniting inflammable gases by sparks moving from contacts, etc. We believe, however, that later developments have quite clearly disposed of these contentions and shown the wisdom of providing in general, for auxiliary equipments on shipboard, the d-c. system; and we understand that some of the vessels which were constructed in 1916 and 1917 with the a-c. outfits have not proved themselves nearly as satisfactory as d-c. installations. The direct current has a distinct and decided advantage in the flexibility and extent of speed control obtainable, and in the obtaining of speed and torque characteristics for hoisting apparatus such as deck winches, windlass and capstan, which cannot be furnished by the a-c. motor. There is no advantage furthermore, on a vessel from the distribution standpoint, in the use of alternating transmission, and a 3 or 4-wire system is more expensive and complicated than the straight 2-wire d-c. distribution. We note that English authorities have recently appeared definitely in print to the above effect, recommending strongly also against the use of a voltage higher than 220 generally throughout the vessel.

With regard to tank vessels, it is possible to furnish motors entirely enclosed, gas and watertight, and where location renders the same desirable, to furnish forced ventilation through the enclosed motor cases. The experience of the tanker *Solitaire*, which was thus equipped, has been to date very satisfactory and two tankers, the *Watson* and *Hillman*, are being constructed with d-c. equipments on the Pacific Coast for the Standard Oil Co.

Marine Types of Electrical Apparatus

Various types of electrical apparatus, generators, motors and controllers are required for the electrical auxiliaries on board ship, according to their location, duty and general requirements, which are discussed in some detail below.

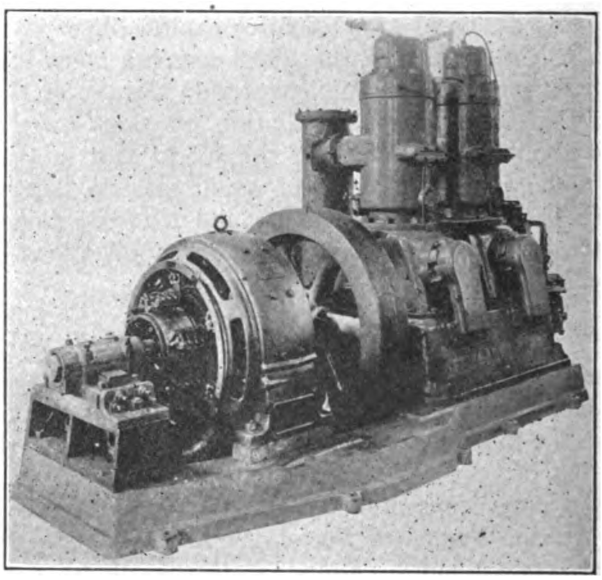


Fig. 2—Oil Engine-Driven Generator Set, 60-Kw. Capacity Suitable for Furnishing Power for Electric Auxiliaries on Motorships

Generating Plant. For steam-driven vessels, steam-operated generating sets are naturally employed, of the reciprocating engine type for small plant equipments in some cases, but turbo generating sets are now almost universally employed for this purpose. These are usually also of the geared turbine type, all parts mounted on a common bedplate as illustrated in Fig. 1, which set is of 100-kw. capacity.

For motorships, oil engine sets are naturally employed with generator mounted on a common bedplate and the flywheel of suitable proportions to assist the regulation and smooth out the voltage fluctuations. A 60-kw. generating set of this type is illustrated in Fig. 2.

As previously explained, on vessels utilizing appreciable amount of electrical power these sets are provided usually two or three in number in accordance

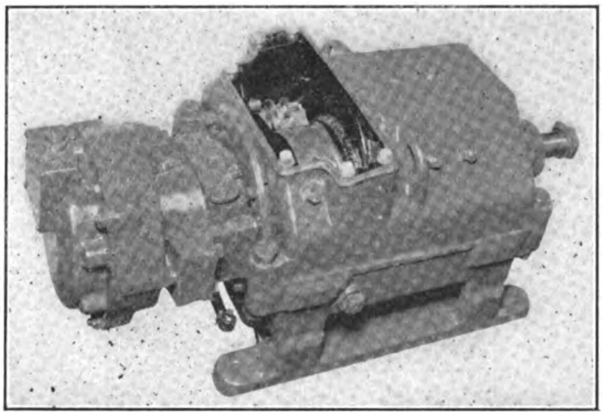


Fig. 3—D-C. Watertight Type of Motor With Disk Brakes for Deck Auxiliaries—Motor Provided With Self Oil Ring Bearings

with the general requirements of the complete installation and the particular ideas of the designing engineers. These sets are now in all cases furnished with open type generators, but in many instances are protected by hoods or metal shields from drippings due to moisture condensation and throwing of oil.

Motors. For driving the various auxiliaries, motors of the open, ventilated or enclosed watertight type

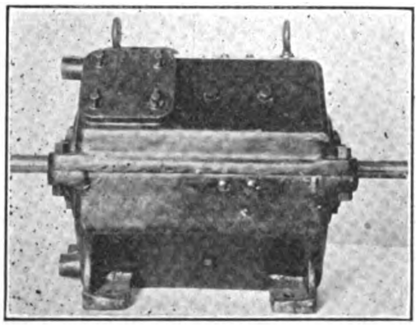


Fig. 4—D-C. Watertight Type of Motor Arranged for Disk Brake (not Shown) Suitable for Deck Auxiliaries —This Motor is Provided With Ball Bearings

are employed, especially the two latter types as but few installations justify the use of entirely open motors.

For deck auxiliaries such as windlass and deck winches, entirely enclosed watertight motors are essential, which must be made strong and sufficiently watertight to withstand such submergence as is occasioned by heavy seas coming over the vessels. This condition therefore, practically necessitates the use of stuffing boxes or similar means around the motor shaft to exclude water, and particular attention must be paid to the design of bearings to insure proper lubrication and operation under roll of the ship. Figs. 3 and 4 illustrate motors of this type, Fig. 3 showing a motor with watertight disk brake mounted and provided with oil ring bearings. Fig. 4 illustrates a watertight

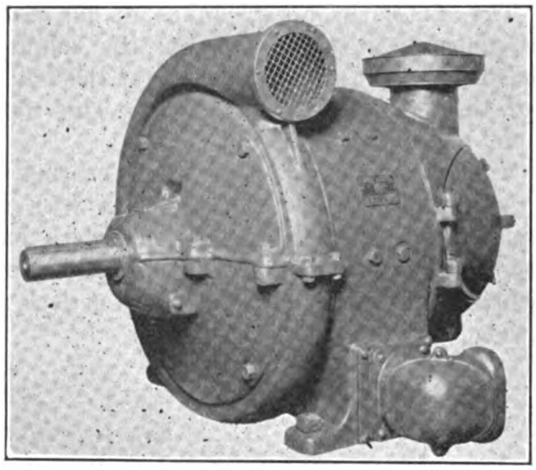


Fig. 5—Enclosed Ventilated Motor Suitable for Engine Room Auxiliaries, Steering Gear, etc.

The involute may be assembled right or left hand and arranged for any angle of discharge. The cowl of the intake may be omitted and top opening closed and air taken in through opening at bottom.

motor with provision for disk brake, not shown, and provided with ball bearings, which are coming into considerable favor for shipboard use to meet the above conditions.

For operation of engine room auxiliaries, such as

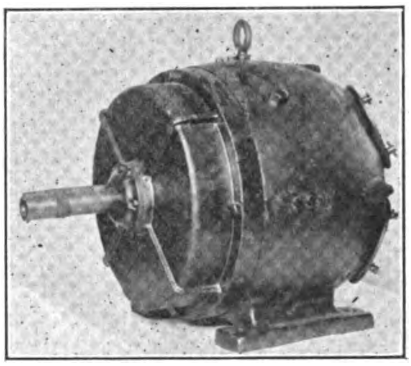


Fig. 6—Enclosed Ventilated Ball Bearing Type Motor Suitable for Driving Engine Room Auxiliaries, Steering Gears, etc.

Air is taken in through mesh in one of the lower front covers and discharged at bottom of casing in rear.

pumps, compressors, etc., open or entirely enclosed watertight motors are occasionally employed but the ventilated type of motor finds particular favor for this purpose as it provides protection against drippings and at the same time permits the use of smaller motor frames for the same duty than when absolutely watertight. Figs. 5 and 6 illustrate motors of the ventilated construction which are provided with internal fans driven from the motor shafts. The involute of the

motor shown in Fig. 5 may operate either right or left hand, depending upon the rotation of the motor, and may be rotated so as to discharge downward and prevent water from entering from above. The cover on the intake may also be omitted, the top opening closed, and air taken through the screen opening at the bottom if desired. This motor is of the oil-ring type. The motor in Fig. 6 takes its air normally through opening at the bottom of the commutator end and discharges through opening at the bottom in the rear through the motor housing. This motor is of the ball bearing construction.

Fig. 7 illustrates a watertight ball bearing motor which is suitable for use in connection with engine room auxiliaries, cargo pumps, etc. where entirely enclosed motor is desired, although the same would not be of suitable design and construction for deck auxiliaries owing to type of frame.

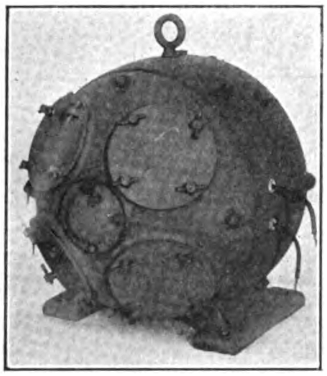


Fig. 7—Enclosed Watertight Ball Bearing Type Motor Suitable for Operating Certain Engine Room Auxiliaries

For steering gears any one of the three types mentioned might be employed, although the steering gear motor is usually in sufficiently protected position to permit of open motor or one at least of ventilated construction.

Controllers. As in the case of motors, several types of controllers are utilized, according to the installation conditions and duty to be performed. These consist of the panel, drum or contactor type, either open. enclosed non-watertight, or watertight.

For the operation of certain of the auxiliaries where watertight constuction is not considered necessary but where it is desired to prevent unauthorized manipulation and render the controller drip-proof, a manually operated panel with hinged doors provided with lock and key is employed, as illustrated in Fig. 8, which shows a manually operated starter and speed regulator, especially suitable for the control of small motors.

Where watertight or gastight protection is desired, a manually operated watertight panel type controller such as illustrated in Fig. 9 is frequently utilized. This shows a motor starter and speed regulator operated by control levers extending through stuffing boxes in the front cover. Gum rubber gaskets with clamping devices are furnished to insure watertightness.

Particularly where installations are in somewhat inaccessible positions, automatic controllers operated by push buttons now find great favor, as the buttons can be located in a very convenient location, and furthermore, the operation of starting the motor is automatic and taken out of the hands of the operator. Such controller is illustrated in Fig. 10 which shows an automatic starting box push-button operated, with gastight enclosing case which is furnished watertight if desired.

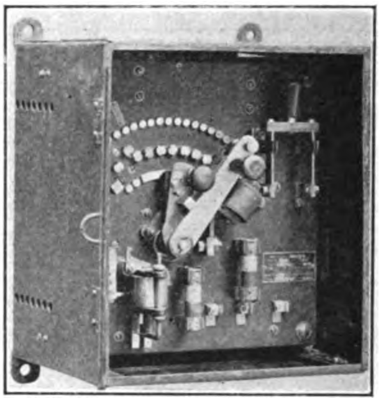


Fig. 8—Enclosed Splash-Proof Hand Starter and Speed Regulator Suitable for Operating Certain Small Engine Room Auxiliaries

For deck machinery, such as winches, windlass, capstan, etc., a manually operated watertight drum is frequently employed which, owing to its watertight construction, can be mounted at the auxiliary above decks. Such a controller is illustrated in Fig. 11.

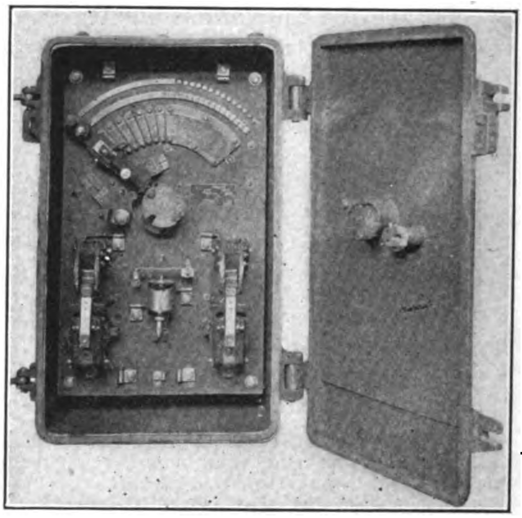


Fig. 9—Enclosed Watertight Hand-Operated Starter and Speed Regulator Suitable for Certain Engine Room Auxiliaries and in Some Cases Deck Auxiliaries

Centralized Control. A method of control of the auxiliaries, particularly on tank vessels, which has found favor in some quarters, mounts the control

apparatus, except for the deck winches and windlass, all on a centralized control board in the main engine room. In the case of tankers this takes the controlling apparatus away from cargo pumps etc. where there is danger from explosive gases. With this arrangement automatic starting controllers are provided for each auxiliary at the board, and there is a push-button station at the auxiliary itself, for signaling to the engineer to start the apparatus, and for stopping the apparatus at the auxiliary if desired. When the signal is received the operator at the switchboard closes the line switches or circuit breakers and the equipment is automatically started. Such an arrangement is illustrated in Fig.12 as installed on the tanker *Solitaire*, and reports from officials of the Texas Co. indicate entire satisfaction with the arrangement.

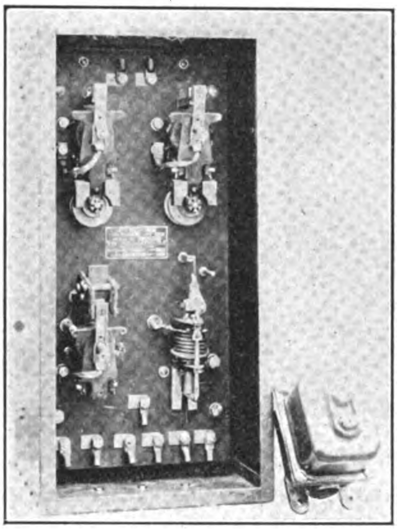


Fig. 10—Enclosed Gastight and Watertight Push-Button Automatic Starter Suitable for Engine Room Auxiliaries

Ship Auxiliary Requirements

The name auxiliaries has come to apply to practically all power-driven pieces of apparatus on board ship outside of the main propelling machinery. The auxiliaries, while differing somewhat for steam and oil engine-driven vessels, have many features in common, the principal difference being that in the case of the oil engine-driven vessels, certain of the pumps, including feed water, condenser water, etc., are replaced by oil pumps, air compressors, etc. While there appears at the present time, to be little if any argument regarding the use of electric auxiliaries on oil engine-driven vessels, the question seems to be still considerably under debate as to their use with steam-propelled vessels, which point we will discuss later.

In all shipboard work reliability is of the first importance and electrical apparatus for ship auxiliaries must be substantially constructed, yet at the same time need not be clumsy as we are frequently led to feel is the case with many of the European designs. Furthermore, each piece of electrical apparatus should be particularly designed for the service and conditions to be met. These conditions need to be carefully *studied* and too great emphasis cannot be laid on this

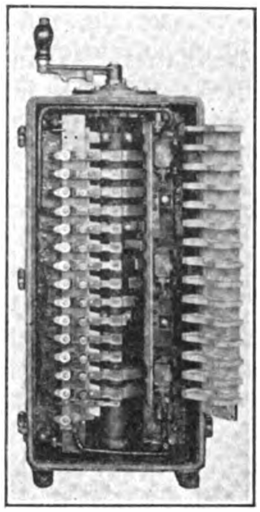


Fig. 11—Watertight Hand-Operated Drum Controller Suitable for Operating Exposed Deck Auxiliaries or Engine Room Auxiliaries in Certain Cases

point, as it is at the root of the successful operation of electrical machinery. Motors on deck will in many cases frequently be awash and hit by heavy seas, also, when the crew is washing down the deck the hose

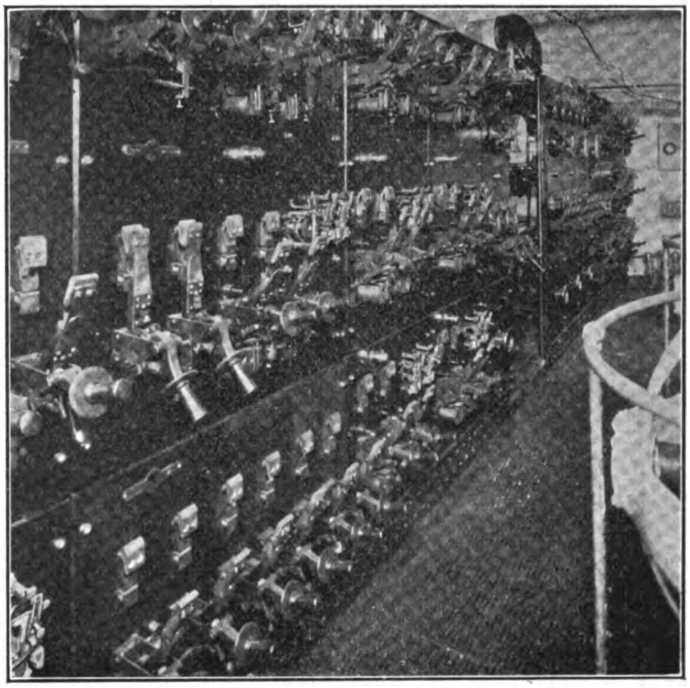


Fig. 12—Switchboard for Engine Room Auxiliaries on Motorship *Solitaire*

will often play over the motors. Vessels trading in tropical climates will have deck machinery subject to the excessive heat of the tropical sun, and all vessels on northern routes have their deck motors at times

subjected to very low temperatures. In the engine room leaky steam pipes are a danger to the motors, and where Diesel engines are employed for the propelling machinery, thought should be given to the protection of motors and controllers from oil fumes and drippings.

Engine Room Auxiliaries. As an example of the engine room auxiliaries which are included in a large oil engine-driven vessel, we give below a list of those supplied on one of our latest motorships, the *Cubore*, of 11,500 tons d. w. c.

Auxiliary	No	H.P.	Location	Motors Type	Motors Open or en.	Control Type	Control Open or en.
Fresh Water Pump	1	5	Floor	Hor.	Encl. Vent	Mag.	Encl.
Turning Gear	1	20	"	"	"	Mult. Switch	"
Booster Compressor	1	25	Platform	Ver.	Open	Mag.	"
Refrigerator	2	5	"	Hor	"	Hand Start	"
Oil Transfer Pump	1	3	Floor	"	Encl. Vent	Mag.	"
Steering Gear	1	25	Steer Room	"	Encl.	Spec.	"
Circulating Pump	2	25	Floor	Hor.	Encl. Vent	Mag	Encl.
Lubricating Oil Pump	1	7½	"	"	"	"	"
200-Ton Ballast Pump	1	15	"	"	"	"	"
Bilge Pump	1	15	"	Ver.	"	"	"
Air Compressor	2	125	Platform	"	Open	"	Open
500-Ton Ballast Pump	1	50	Floor	Hor.	Encl. Vent	"	Encl.
Lub. Oil Purifier	2	1	For'd. Blk.	"	Encl.	Hand Start	Open
Fuel Oil Pump	2	3½	Floor	Hor.	Encl.	Mag.	Encl.
Sanitary Pump	1	7½	"	Hor.	Encl. Vent	Mag.	Encl.
Lathe	1	1½	Platform	"	Open	Mag	Encl.
Grinder	1	3	"	"	"	Hand Star	Open
Drill	1	2	"	"	Open	"	"
Generator	2	100 k.w.	Floor	Oil engine-driven			
Generator (Emergency Set)	1	100 kw.	"	Geared steam turbine-driven			

For a steam-driven vessel many of the above auxiliaries will be similarly used in the engine room with the replacement of the several oil pumps and engine circulating water pumps by boiler feed, condenser, condensate pumps, etc. In connection with the pump equipments either piston reciprocating or centrifugal pumps are generally used with water or steam service systems, the centrifugal pump being especially favored for engine circulating, condenser, and sanitary service, the selection however, usually depending upon the opinion of the designing engineers. Some form of rotary type pump is usually employed for oil service systems. For reciprocating and rotary pumps the constant-speed shunt-wound motor is best adapted, but for the centrifugal a wise provision includes a small percentage of series winding to prevent excess speed and loading of the motor. Field control of a wide range is frequently provided for many of these pump equipments, in some instances to vary the pump delivery, but in the case of the centrifugal pump a small amount of field control is sometimes added to advantage to assist adjustment of the load and speed.

The air compressor and engine turning motors can be provided with an appreciable amount of compound winding to advantage, and machine tool motors such as lathe, drill, etc. would usually require shunt-wound variable-speed motors.

The control for these engine room auxiliaries would be generally by the hand-operated watertight panel or the push-button watertight construction as illustrated in Figs. 9 and 10 unless the centralized control previously described were utilized.

Deck Machinery. The deck machinery equipments, consisting of windlass, deck winches, capstan and steering gear, may be considered separately to advantage.

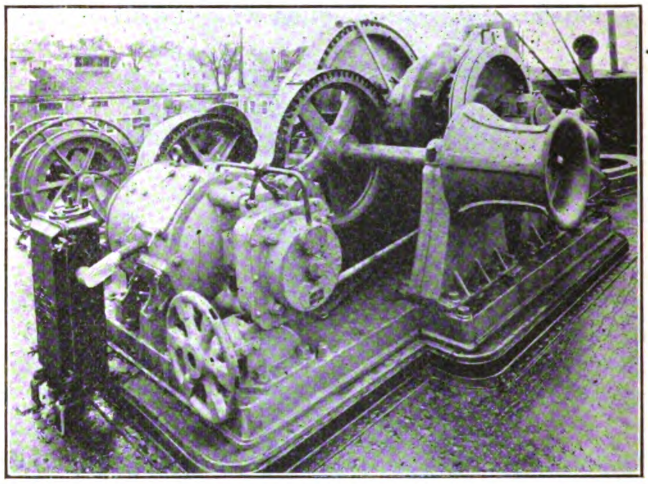


Fig. 13—Windlass Equipment Installed on Motorship *Solitaire*

Watertight oil ring bearing motor with disk brake and watertight drum controller.

Windlass. For the windlass equipment a watertight motor is essential, and a manually operated drum controller, if installed on and operated from the deck. Frequently however, control equipments are provided non-watertight and installed below deck with shaft extensions through stuffing box, or a contactor equipment remotely controlled with small watertight master on the deck and non-watertight automatic panel below deck. A compound-wound motor can be used to the best advantage usually for the anchor windlass, particularly when of the spur-geared type, and provisions must be made in the control for stalling the motor on any controller point in case of fouling the anchor on the bottom or jamming of the gear. Fig. 13 illustrates a windlass equipment as installed on the tanker *Solitaire* with manually operated watertight drum.

Deck Winch. The auxiliary upon which probably more thought and study is being given at the present time from an electrical standpoint, than any other on shipboard, is the cargo deck winch. This is an especially important piece of machinery on a vessel handling miscellaneous cargo; and reliability of operation, and range of speed control in both hoisting and lowering, are of prime consideration. Deck winch motors should

be of the general construction as shown in Figs. 3 and 4, and the control, if manual, would be similar to the watertight drum shown in Fig. 11. An illustration of a deck winch which has been particularly designed for the service, is shown in Fig. 14. With this arrangement drum controller and resistances are all mounted within the winch base, the rheostats being ventilated through adjustable openings in the sides. Fig. 15 shows an electric winch as installed on the *Solitaire,* with manually operated watertight drum and separate

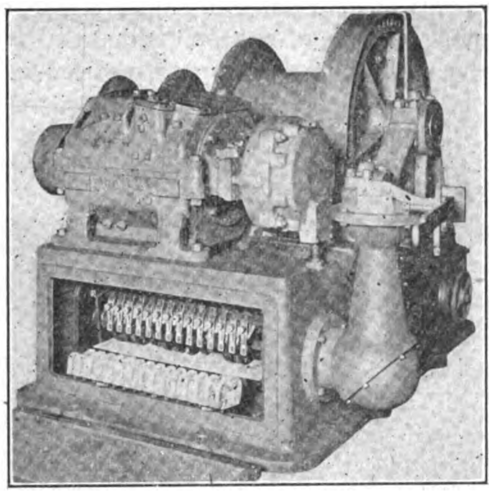


Fig. 14—Self-Contained Deck Winch with Exposed Watertight Motor and Disk Brake—Drum Controller and Rheostat Mounted in Base

rheostat box arranged especially for ventilation, when in operation, by means of a hand wheel.

Much discussion has been had of late with regard to the exact type of control to be furnished for deck winches and the results to be accomplished. One manufacturer is strongly advocating at the present time, the electrically operated winch, provided, however, with mechanical load lowering brake in place of the customary dynamic electric lowering control. While differences of opinion naturally exist on these details, one point is obvious: That the ideal electric winch is one which provides as nearly as practicable, a straight horse power curve, accommodating its speed automatically to the value of the load and permitting the handling of light and heavy loads without the necessity of changing gears; also that it gives in lowering as nearly as practicable, corresponding range of speeds for heavy and light loads down to the empty hook. And it must be borne in mind that time gained in the hoisting and lowering of the empty hook is that much clear gain in loading and unloading the vessel.

In the case of deck winch equipments and anchor windlass as well, it is the practise to provide a mechanical brake on the motor shaft, electrically operated, to prevent falling of the load in case of failure of voltage.

An arrangement of control for the deck winches which has been used to some extent and was recently illustrated in the cases of the motorship *La Paz,* provides a small deck housing between or adjacent to the hatches and in the center of a group of winches. In this small deck housing is placed the main controlling apparatus of the contactor type, as well as the rheostats all of open construction. At the winch itself is provided a small watertight master controller carrying contacts only for the operation of the contactors within the deck housing. This arrangement we believe is worthy of serious consideration as it groups the apparatus together to advantage, makes the apparatus readily accessible, and permits of good ventilation to the rheostats, thus permitting less capcity and smaller resistances.

Capstans. Capstan equipments, where used, are frequently so arranged as to permit installation of the driving motor in a compartment below decks, thus allowing an open or at least a self-ventilated motor, which is usually furnished heavily compound-wound to provide the varying torque characteristics necessary with this equipment. The control, in its simplest form, may be a plain starting hand-operated or push-button controller, but the best practise provides stalling features and dynamic or armature shunt control on one or more points in either direction for use in paying out cable. The motors should be usually provided with an electrically operated mechanical brake as the drive is often through gearing efficient enough to permit overhauling.

Steering Gear. The early stages of development of the electric drive as applied to steering gears, is quite generally covered by the writer's paper before the

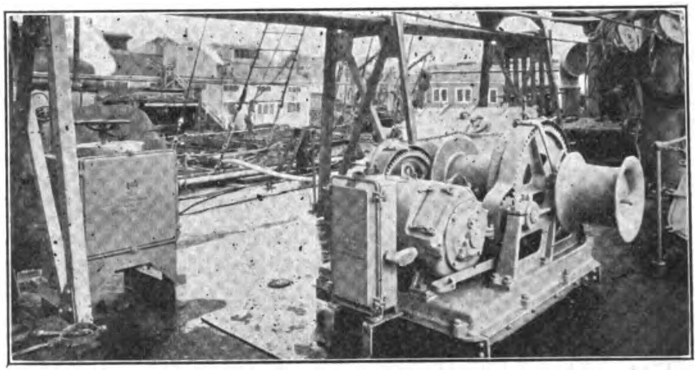


Fig. 15—Deck Winch Equipment Installed on Motorship *Solitaire*

Watertight ball bearing motor with watertight drum controller and watertight rheostat box (shown at left) ventilated by means of hand wheel.

A. I. E. E. in May 1914, which describes in detail the direct application of electric drive where a motor is geared directly to the transmission, frequently of the screw gear type, as illustrated in Fig. 16. With this arrangement the motor is operated by a contactor panel remotely controlled from the bridge, usually on the non-follow-up system, although electrical follow-up control has been designed and some times employed.

This direct electric application is simple in design

and effective and reliable in operation, as clearly demonstrated by extended experience which the Navy has had, and has led furthermore by its simple and reliable arrangement of control, to the abandonment entirely of the use of the follow-up gear. Opinions among seafaring men are very much divided still however, as to the wisdom of the use of the non-follow-up gear in merchant marine, although it is being tried in a number of cases with perfect success.

This direct method of drive, however, is accompanied usually by a very inefficient mechanical transmission, the screw gear for instance giving an efficiency usually of 30 to 40 per cent. As a means therefore, of providing more efficient transmission, the hydraulic speed gear is now frequently employed particularly for installations of large horse power where the saving, owing to the more efficient transmission, is very marked. With this arrangement the constant-speed motor operates the hydraulic pumps which supply oil to hydraulic rams operating the rudder cross-head, this hydraulic transmission therefore, entirely replacing the ordinary screw or other type of mechanical gear. Such an arrangement is shown in the Fig. 17 which covers the hydroelectric steering gears as constructed for the scout cruisers Nos. 4 to 13. This navy equipment has duplicate driving motors of 60 h. p. each and duplicate pilot motors for operation of the valve mechanism of 1½ h. p. each. The control for the main and pilot motors is by the contactor panels shown in the foreground, and the control from the bridge is furnished by operation of the small pilot motors through the control panel on the non-follow-up system.

For merchant vessel work, open or ventilated motors are usually employed. If for the direct-connected electrical type they would be compound-wound, and for the hydraulic system shunt-wound. For the control of the direct-connected type, contactor panel would be supplied in the steering gear room with steering stations at such points as desired, with a selective switch on the control panel to delegate the control to any one of these. For the hydraulic system the control equipment resolves itself usually to simply a starting panel for the main motor and in merchant work the control of the valve with the hydraulic gear has been frequently by means of a hydraulic telemotor or tiller rope transmission. Electric pilot motor control, however, can and has been supplied in either of the follow-up or non-follow-up type.

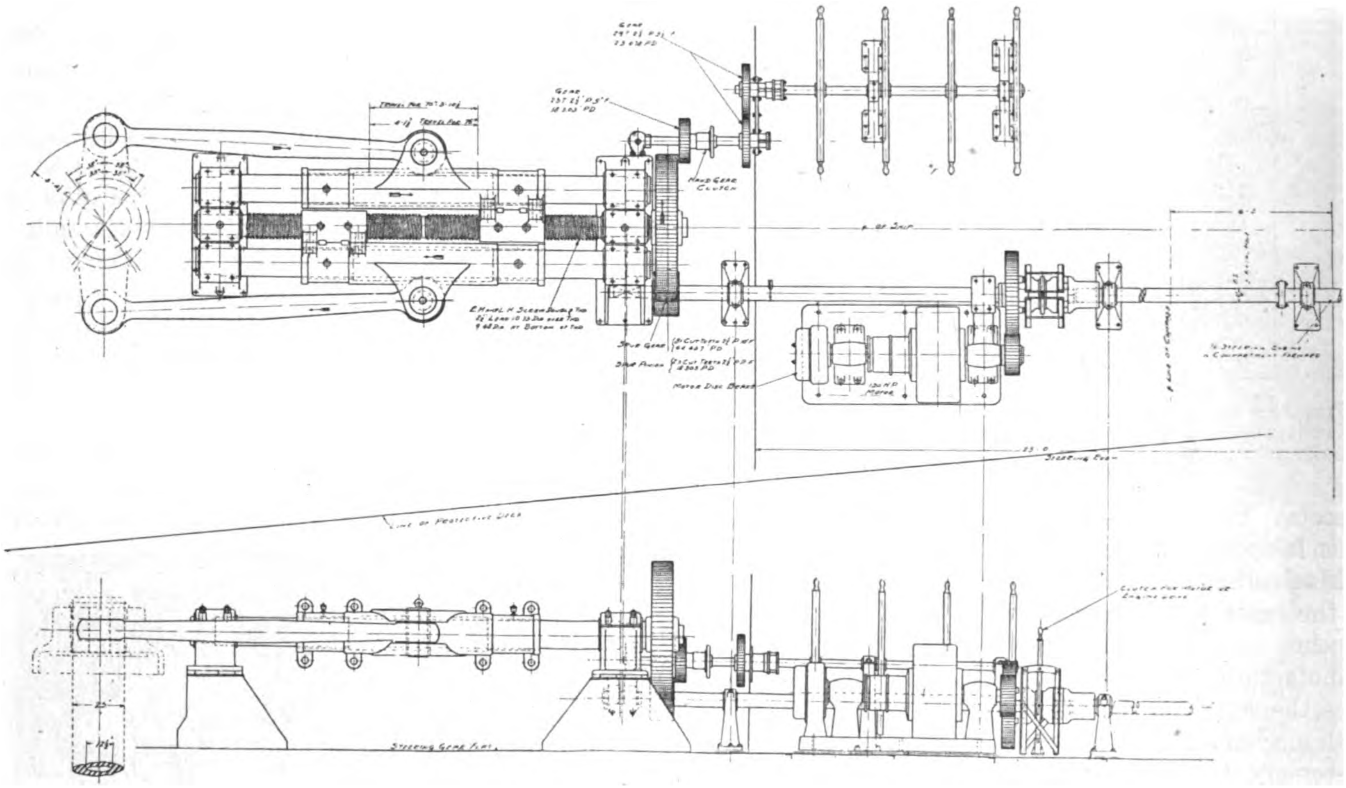


Fig. 16—Direct Application of Electric Drive to Steering Gear of the Screw Type With Open Type Motor (This Equipment as Installed in the Navy Provided With Both Electric and Steam Drive).

Advantages of the Electric Drive

It has been shown by experience, that the electric drive of the auxiliary machinery has resulted in a considerable saving in fuel consumption of a vessel. Also, the more efficient the propelling machinery, the greater the saving that may be otained by the adoption of electric auxiliaries. This is due to the fact that with steam-driven auxiliaries, the exhaust steam from the auxiliaries in the engine room is utilized principally for feed water heating. Where the total steam consumption, including propelling machinery, is

heavy, a larger quantity of this exhaust steam can be efficiently utilized than where the total steam consumption is not as great. This applies only to such auxiliaries as are in constant use during the voyage. It is evident therefore, that until the limit of feed water heating has been reached, the reduction in the steam consumption taken by the auxiliaries will not have nearly as great effect on the fuel consumption, as would be the case after this critical point has been passed. The limit of feed water heating is more quickly reached of course in the case of the most efficient propelling machinery. Ideal conditions would be obtained when the exhaust steam from the turbo generator for instance, is just sufficient to obtain the limit of feed water heating during the voyage. With turbine drives the surplus of exhaust steam is sometimes turned

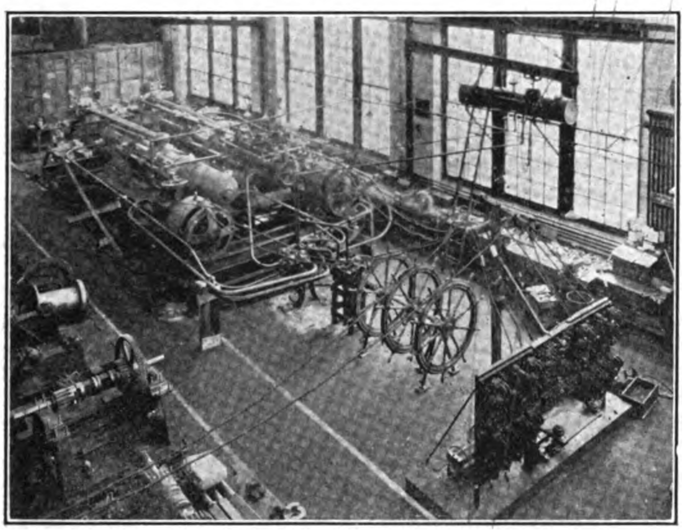


FIG. 17—HYDROELECTRIC STEERING GEAR (IN MANUFACTURERS' SHOP) FOR NAVY SCOUT CRUISERS NOS. 4 TO 13

Two 60-h. p. main driving motors and two 1.5-h. p. pilot valve motors are provided, one main and one pilot motor being furnished as a standby. Control panel shown in foreground.

into the low stage of the turbines, but how efficient use can be made of more auxiliary exhaust steam, than above outlined, as necessary for feed water heating and some times other minor purposes, is not apparent.

The above applies particularly to vessels using steam for their main propulsion. For ships operated by Diesel engines or Diesel electric drive, it is obviously of great advantage to operate all the engine room auxiliaries by electricity as it is largely a question of the efficiency of electric transmission with a large and reliable generating unit, against a number of small inefficient oil or steam engines, and it is naturally desired to avoid the generation of steam in any quantity on a motorship.

Aside from the engine room auxiliaries referred to above, attention is particularly drawn to the deck auxiliaries which are located some distance from the generating plant and where great losses would take place in the steam pipes feeding them. In these cases the electric drive is by far the most efficient method, irrespective of whether the vessel is steam or oil engine-propelled. It has always been noted by the writer that there is an almost complete absence of reliable figures on steam consumptions of steam-driven auxiliaries and inquiries usually bring out simply the information that an 8 by 10 engine for instance, etc., is used, without any data as to its actual efficiency or steam consumption. Some idea can be obtained of the loss of steam on the steam type of auxiliary when it is remembered that it is frequently considered essential to keep steam on the winch and windlass engines in cold weather to prevent the cylinders cracking or pipes bursting from freezing. The steam steering engine is a particularly noteworthy example of the wasteful use of steam as it is in effect only a steam ram taking steam full stroke with valves always left cracked a small amount.

The electric motor is always operating at a point of high efficiency and does not suffer in this respect from change of climatic conditions. Furthermore, the power transmitted through electric cables is practically a constant quantity regardless of temperature conditions, while steam transmission is affected very decidedly thereby.

The electric drive in addition to its convenience, adaptability and ease of operation, has the further merits of being available at any instant without preliminary warming up, or as above stated, the losses while standing idle with the steam plant.

Space, Weight and First Cost. Comparative figures which have been reliably obtained indicate generally some increase in the weight and space occupied for the electric over steam drive. In some cases however, such as the steering gear, an actual saving in space and weight is usually effected with the electric, and in other cases the difference is very slight. In the matter of first cost, it is also apparent from such figures as have been available to date, that electrical auxiliary machinery is roughly about 20 per cent more expensive than steam, except in case of deck winches where the difference is more, sometimes 100 per cent. It is also found that an oil engine-propelled motorship is about 30 per cent more expensive in first cost than a steam-driven vessel and that strange as it may seem, the Diesel electrically propelled ship is slightly less expensive than the straight Diesel owing to the smaller and higher speed oil engines which it is possible to utilize. These figures of first cost however, we feel are influenced to a considerable extent at the present time by the lack of a developed line of apparatus on the part of many manufacturers and that in many instances full development costs have been charged against the first installations of electric auxiliaries which would be absorbed in later installations.

As against these disadvantages of first cost and weight, are obtained the advantages of:

1. Suppression of heat in spaces adjacent to the

gear and transmitting lines, which is of importance in certain cases.

2. Elimination of accidents due to freezing and bursting of steam pipes, cylinders, etc.

3. The reduction of vibration and noise and an increase in the habitability of the ships due to these factors. This is particularly marked in the case of the steering gear.

4. The simplification and flexibility of control, operation being obtained readily from the most convenient point.

5. The obtaining of mechanisms as outlined above which are very much more efficient in operation than the steam equipments. This is the most important consideration.

Economy of Operation. That without question a very appreciable saving in the fuel consumption can be obtained by the use of electric drive, there is little doubt, and L. Miller, an English writer, has recently stated that in the modern equipment with propelling machinery consisting of double reduction geared turbines using superheated steam, a saving of 8 to 10 per cent of the fuel bill can undoubtedly be obtained by the adoption of electric drive on the auxiliary machinery. He further states that tests recently made on a modern equipment, as far as the propelling machinery was concerned, and where steam-driven auxiliaries had been adopted, the steam consumption in the main turbine was 10 lb. per shaft horse power, and the steam consumption of the auxiliaries running during the voyage was found to be 30 per cent of the total steam consumption of the whole vessel. This figure is further borne out by observance and tests in this country and shows what an important part of the total load of the vessel is made up of the auxiliaries in the case of the steam equipment, and the opportunity for economy in this department.

Another important consideration is the fact that experience shows on motorships already constructed with electrical auxiliaries, that in port the power required during the period that the deck winches are handling the cargo is about three times the amount required with the auxiliaries at sea. Investigation of cargo handling vessels in general has shown furthermore that winches are idle five to eight times the amount of time they are in operation during an eight hour day of work. With electric drive, power is completely shut off while the winches are out of operation, but in the case of the steam equipments condensation and leakage continues the same.

While we have numerous general advices to the effect that the fuel consumption of steam-driven auxiliaries is at least ten times that of electric, etc., we have some specific figures from oil engine-driven vessels of the *Benowa* and class which are in operation on the Chilberg line and plying between Australian points and the Pacific Coast. The following figures are given for two vessels, the *Benowa* equipped with electrical auxiliaries, and the *Cethana*, equipped with steam auxiliaries:

	Benowa	*Cethana*
Net registered tonnage........	1788	1800
Propulsion....................	2–500 h. p. Diesel eng.	2–500 h. p. Diesel eng.
Average daily fuel consumption main engines...............	1350 gal.	1365 gal.
Average daily fuel consumption-donkey boiler..............		557 gal.
Average daily fuel consumption-auxiliary engines............	42.5 gal.	
Total daily fuel consumption...	1392.5 gal.	1922 gal.
Per cent of total fuel used for auxiliaries..................	3.4%	29%

The above shows a saving of approximately 25 per cent in fuel consumption due to electric auxiliaries. Examination of the records of other ships shows a similar percentage gain.

The above figures were obtained from the logs of these vessels and are corroborated furthermore, by communications from the officials of the Line. We, moreover, would understand that for two of the vessels of this class for a period of four days in port handling cargo eight hours a day, that the total fuel consumption of all auxiliaries in operation was 5.3 times more for the steam-operated than the electric. In handling miscellaneous general cargo during this period also, approximately 20 per cent more cargo was estimated as handled with electric winches than with steam. The steam-equipped vessel was supplied with two donkey boilers and eight 7 by 10 steam winches.

We have incidentally, in addition, advices that for two sister ships recently constructed and operating in the Pacific, one equipped electrically and the other with steam auxiliaries, for a period of six months the repair bill on boilers and steam winches was $3800.00, while repairs on the generating sets and electric equipment for the same period amounted to only $92.00. We appreciate the fact of course that this was undoubtedly an unusual condition, some accident probably happening to the steam plant, but we emphasize the point that repairs are necessary to steam equipments and that if some repairs are occasionally necessary for the electric, it should not be considered a matter of discredit to the electric drive.

Correct Atmosphere of Thought

In the consideration of the use and adoption of electricity for ship auxiliaries, it has been necessary to develop a new line of thought in the minds of steamship owners, naval architects, marine engineers, etc., and while we believe that still more must be accomplished in this respect, considerable progress has been made.

This progress is noteworthy, especially in view of the opposition which had been encountered to the use

of electricity until recently, from many of the above interests and manufacturers of steam apparatus in general. In some instances in the past these interests have freely stated that they would use their best efforts to defeat the use and adoption of electric auxiliaries on merchant vessels.

We have made but little reference to the wide application of electricity in the American Navy and the very satisfactory results which have been obtained from practically all of its apparatus so operated. This at least in a general way, is known by the majority of the members of these two societies, and further, has, we believe, had a very important bearing on gradually changing the mental attitude with reference to the merchant field. It is frequently remarked however, that results can not be obtained on merchant ships similar to the navy, owing to the much higher class of operators on the navy vessels and the fact that the average freight vessel does not carry men in any way familiar with electrical apparatus. You frequently used to hear also remarks made in connection with a contemplated vessel or one under construction, that the general use of electricity would require a generating plant of possibly 100 or 200-kw. sets, whereas the generators which they had, or had contemplated purchasing, were in the neighborhood of 10 to 15 kw.

It is obviously essential that a ship using electricity to any extent should have a power plant of equivalent size, and equally important that such vessels should be provided with at least one operating engineer who is sufficiently versed in electrical matters to be able to make slight adjustments and repairs in the same way that steam engineers can repair steam machinery and consider the same really as a part of their regular duties.

Owing to the general unfamiliarity of the operators in the past with electrical equipment, it has frequently occurred that criticisms were made of the performance of the electrical apparatus, although defects or casualties were of a minor nature, whereas a similar casualty to a steam device would be taken entirely as a matter of course. As an instance of this mental attitude, we have been reliably informed that in the case of one of the motor ships recently put into operation in this country, several trouble reports had been received outlining in some detail minor defects experienced with the electrical apparatus; but in the case of the Brown telemotor for steering gear where trouble was experienced for about five hours on one occasion, the incident was taken entirely as a matter of course by the officers of the vessel and no report whatever was submitted, it being later only noted from the ship's log. It is therefore, particularly desirable to educate, in a general way, the officers of the vessels in the merchant service to the use of electricity, and although they may not have in any sense the experience or training of electrical engineers, once they become familiar with its general use, the major part of the present criticisms will have disappeared.

Some failures of electrical equipments have been naturally encountered and reports of these matters have been naturally stressed considerably, as bad news always travels faster than good, but in the majority of cases when the actual situation is understood, there are found to be very definite reasons for the change back to steam apparatus. We have heard for instance, that in the case of the large cargo vessel *Minnesota*, consideration is being given to the removal of the electric winches and providing same with steam. While we are not thoroughly informed as to all the difficulties encountered with these electric winches, which were installed quite a number of years ago, we are led to believe that if electric winches of the latest type and design were provided, that most of the criticisms would be taken care of. We trust that the manufacturers of the electrical equipments for the winches as now installed, are making a careful study of this particular situation and possibly can give us additional comments regarding the matter this evening

During the war the Petroleum Transport Co. constructed four oil barges which were provided with propelling machinery consisting of oil-fired boilers, steam turbines, operating two screws driven by a-c. motors, these motors being controlled from a central station by one master controller with straight line lever motion similar to steam valve mechanism. We understand that the Petroleum Transport Co. now contemplates the removal of this propelling apparatus and the installation of reciprocating steam engines. A very careful check of this situation has shown that the difficulty has been almost entirely one of operating conditions, that the vessels were designed for low speed of about 8½ knots and to make short cruises from port to port along the Gulf Coast; therefore being supplied with a very limited fuel and water capacity. It was later decided however, to put these boats on relatively long trips, from Tampico to Miami for example, for which they had neither the fuel nor fresh water capacity. Salt water has been apparently, the primary cause of all the troubles that these ships have experienced. With salt water in the boilers they primed considerably, resulting in deposit of salt and grit within the steam turbine, producing particularly serious corrosion of packings and shafts, and resulting in some cases, in a complete breakdown of the turbines. We are informed furthermore, that the engine room crews on these ships had not, on the whole, measured up to a high standard and in many cases carelessly wasted their fresh water supply. We understand that the new equipments are to comprise considerably larger boilers and more powerful engines with a desire to increase the speed of the boats. We are not informed as to how the question of fuel and water capacity is to be met, we are pleased however to report that although these equipments are to be removed,

no criticism whatever was found with the electrical apparatus; in fact its operation was reported to be highly satisfactory.

Conclusions

In conclusion, we feel that while the growth and adoption of electricity in this field was very slow for many years, that within the last three or four years in particular, definite and very rapid progress has been made. The popularity of the electric gear with those who have been concerned in its operation, would seem to have been well established where it has been given a fair and impartial trial.

The more rapid adoption of electric drive is now receiving decided impetus from the introduction of the fuel oil engine, and we now look for its general use at a very early date, as soon as many of the present equipments now being installed have been tried and the operators become familiar with the apparatus, and with the general thought that electricity instead of steam is operating their equipments for them.

We trust too, that everyone may be of an open mind on this subject, giving full opportunity for correction of first errors in later designs, as we feel it is still without question in the development stage, and where unfavorable reports are heard to assist in analyzing and reporting the true conditions which have led to failures and criticisms.

It is with a sense of gratification, therefore, that we feel our predictions of a number of years ago are being rapidly fulfilled.

Reestablishing Service in a D-C. Edison System after an Interruption

BY RAYMOND BAILEY
The Philadelphia Electric Co.

MOST of the large central station companies have certain areas to which 125–250-volt d-c. energy is supplied. In the days gone by, this direct current was generated in a number of stations having d-c. engine-driven generators. These generating stations were tied in by means of feeders with the "mains" which were laid in the streets and connected together to form an extensive network; the entire combination being known universally as an Edison system.

As the a-c. systems were developed and put into operation, the Edison networks were supplied with energy from them through motor-generator sets and later by means of synchronous converters.

Storage batteries were installed throughout the d-c. areas to carry the load of any station for a short time in case of trouble with generating equipment. It is not practicable in most cases to install enough battery capacity to carry the load for but a comparatively short length of time. The rapid growth of a-c. systems and in some instances that of the Edison systems has led to interruptions of pronounced magnitude and duration.

Experience indicates that there are, at times, interruptions of such length as will completely discharge the stand-by batteries, thus making it necessary to bring the system voltage up from zero to normal with d-c. machines. When d-c. generators are used for this work no trouble is experienced as the machine voltage can be reduced enough to permit their being connected to the network without taking an excessive load. That a considerable reduction in generator voltage is needed to make it possible to put the machine on the "line" will be evident when it is remembered that the network of d-c. mains with connected apparatus forms a very low resistance path for the current.

The extensive use of synchronous booster converters for Edison systems has complicated the problem as it is impossible to reduce the voltage of these machines much below 90 per cent of normal.

It is evident that in addition to taking the usual precautions to insure continuity of service, it is necessary where synchronous converters are used to supply the d-c. network, to provide means for readily reenergizing it should a complete interruption occur.

It may be possible to reestablish service by any one of the methods:

a. Reduction of a-c. system voltage.

b Use of a number of motor-generator sets.

c. Simultaneous closing of all machine circuit breakers.

d. Sectionalizing the network.

e. Use of load-limiting resistors in converter circuits.

f. Operation of converters on reduced voltage taps.

There are some a-c. systems which are so arranged and whose operating conditions are such that it is possible to isolate that part which supplies the Edison network and then reduce the voltage for the purpose of reestablishing service. The a-c. voltage is varied to give the desired d-c. voltage during the reenergizing period. This would appear to be a satisfactory method for reestablishing service where it is possible to carry it out.

If motor-generator sets are provided for restoring service, a fairly high percentage of the total machine capacity would consist of these sets. The disadvantages of this arrangement are in the larger space required by the

motor-generators and their lower efficiencies, as compared with the converter.

Closing the d-c. breakers of all of the converters on the system simultaneously in order to get the converters back on the line, has the advantage that it requires little additional equipment, but if Edison load is large compared to the generating capacity, it might be rather difficult to carry out successfully. This arrangement requires considerable control wiring between stations.

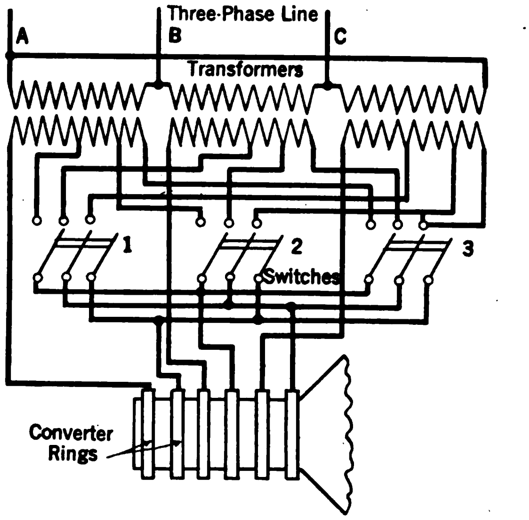


Fig. 1—Diagram of Connections Between Converter Transformers, Starting Switches and Converter Rings for Secondary Starting

Switches Nos. 1, 2 and 3 are interlocked so that only one switch can be closed at a time.

Sectionalizing the network in order to facilitate restoring service is very expensive and in many cases cannot be carried out for practical reasons.

It is not a good plan to use load-limiting rheostats except in certain special cases, because they are expensive and require considerable space which is very costly and often not available in the metropolitan districts.

It is likely that the method of restoring service which involves the operation of the converters on reduced voltage taps may prove satisfactory in certain systems. When secondary starting is used, the connections between transformers and converters for reduced voltage, starting and running, are as shown in Fig. 1. Voltages of 50 per cent, 75 per cent and 100 per cent may be obtained by closing respectively switches Nos. 1, 2 and 3. Fig. 2 shows the connections for high-tension starting. In this case voltages of 58 per cent, 72 per cent and 100 per cent are obtained by closing switches Nos. 1, 2 and 3 respectively.

Which one of the reduced voltage taps is used for starting depends upon the design of the converter. Manufacturers of synchronous booster converters state that these machines have been operated under load at reduced voltage and no trouble need be expected in the way of unstable operation, etc.

A comparison of the two schemes of connections will show that when rated direct current is carried on the converter, none of the transformer windings is overloaded provided the reduced voltage taps are on the low-voltage side of the transformer (Fig. 1), but the high-voltage windings are overloaded if the reduced voltage taps are on the high-voltage side (Fig. 2). If 75 per cent of running voltage is used to start the converter, 80 per cent of each of the high-voltage windings should be connected in the circuit which will give approximately the desired voltage. The exact per cent voltage obtained is equal to

$$\frac{100}{\sqrt{3} \times 0.8} = 72.5 \text{ per cent.}$$

This change in ratio of transformation will produce an overload current of 25 per cent in the high-voltage winding when the converter is carrying rated direct current. It is likely that most converter transformers, even though rated at maximum, will carry this overload current for at least one hour, as the core losses are much reduced due to the fact that only 72.5 per cent of rated voltage is applied. When the entire high-voltage windings are used in the *Y* connection to obtain a very low d-c. voltage, full-load current on the converter produces no overload on the transformers

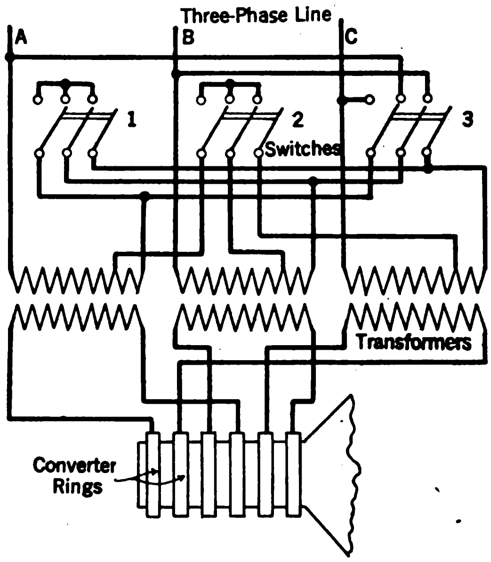


Fig. 2—Diagram of Connections Between Converter Transformers, Switches and Converter Rings for Primary Starting

Switches Nos. 1, 2 and 3 are interlocked so that only one switch can be closed at a time.

and the core losses are much reduced, as only 58 per cent of rated volts is applied.

In order to follow the proper procedure in reenergizing the network it is necessary to have the equipment arranged so that the maximum d-c. voltage of the converter operating on a certain transformer tap is approximately equal to the minimum voltage of the converter when running on the next higher tap.

It is probable that where converters are started

on 75 per cent of running volts, an additional reduced voltage tap will not be necessary. If 50 per cent of normal voltage is used for starting, a tap giving approximately 75 per cent volts will be required in order to obtain the necessary range of d-c. voltage. Table I gives voltage combinations for both primary and secondary starting and shows that with a 30-volt booster, the maximum voltage on certain taps does not equal the minimum voltage on the next higher tap. It is to be expected that under the conditions met in practise, it would be possible to make these voltages practically meet.

TABLE I

Tabulation of d-c. voltages obtained from the converters when operating on different transformer connections.

Secondary starting					Primary starting				
		D-c. volts					D-c. volts		
Switch closed	Tap	Min.	Neut.	Max.	Switch closed	Tap	Min.	Neut.	Max.
No. 1	50%	98	128	158	No. 1	58%	117	147	177
No. 2	75%	161	191	221	No. 2	72%	155	185	215
No. 3	Run	225	255	285	No. 3	Run	225	255	285

When the system balance is maintained by neutral connections on the converter transformers, high-tension starting is best, as the neutral can be closed during the entire reenergizing process, thus maintaining the desired balance. If secondary starting is used, the neutral connection can not be closed until the converter is operating on the running connection, thus making it necessary to maintain the balance in some other way.

In order to illustrate this method of reenergizing the network, assume a 200,000-ampere d-c. load (270 volts at bus) which before an interruption was carried by five of six 10,000-ampere converters in each of four stations. No reduced voltage tap in addition to the 75 per cent starting tap is provided. The load dispatcher would supervise the entire operation which could be carried out somewhat as follows:

The first step would be to start five machines in each station, four of which would be left running on the 75 per cent starting tap and the fifth on the running tap, all at maximum buck; the d-c. voltage of the converters on the starting taps being 161 volts and those on the running connection 225 volts. The breakers of the machines operating in the different stations on the starting tap would then be closed as nearly at the same time as possible, picking up about 6000 amperes per machine. The d-c. voltages of these machines would then be increased to maximum boost (approximately 221 volts) which would increase the amperes per machine to approximately 8200.

These figures on the load picked up by the machines at certain voltages are based on the assumption that the connected load does not change during the reenergizing period. Experience indicates that this assumption is the proper one to make as it introduces a factor of safety.

The one converter in each station operating at maximum buck on running voltage would then be connected to the d-c. system and fully loaded. This would relieve one converter in each station operating on the starting voltage, which could then be disconnected, changed over to running voltage, and loaded; which would in turn relieve another machine, which could be changed over to running voltage. This process is repeated until all machines are changed over to running voltage and the system voltage brought up to normal.

It is of course necessary to have arrangements made so that the booster fields of the converters can be supplied from some separate source of energy, such as the battery or the one converter which is operating on the running connection. Sufficient voltage for the booster fields could not be obtained when the converters are operating on the starting tap if the fields are supplied from the terminals of the converter.

If a reduced voltage tap in addition to the starting tap is provided, one more step is introduced into the operation of picking up the load, but on the other hand, less load is picked up when the machine breakers are first closed, which is advantageous.

It is advisable to energize the shunt fields of the converters from some external source during the starting period in order to secure correct polarity which will save considerable time in reestablishing service.

It can readily be seen that making provision in new installations for this method of picking up the load requires very little expenditure of money or space in the station, the addition of a small amount of switching equipment, transformer taps and connections being all that would be required in most cases. As a matter of fact the greatest difficulty lies in adapting the present installed equipment for operation with the new. Differences in starting voltages of the converters installed in the same station complicate the problem to a certain extent.

If for example, a substation has converters all arranged for secondary starting but some of them have 50 per cent starting taps and the remainder taps for 75 per cent, it might be possible to obtain the desired results as follows: Equip the high-voltage side of the converter transformers with oil circuit breakers for connecting the windings Y (normal connection delta), with 80 per cent of the turns of each phase in the circuit. After the machines have been started they would be closed in on the network with the 50 per cent machine operating with 50 per cent secondary winding and full primary winding delta-connected, and the 75 per cent machine with 75 per cent secondary winding and 80 per cent primary winding Y-connected. The next higher voltage would be obtained on the 50 per cent machine with full secondary and 80 per cent pri-

mary winding Y-connected, and on the 75 per cent machine with 75 per cent secondary winding and full primary winding delta-connected. The last or running voltages would of course be obtained in the usual way.

Where three-wire converters with a high unbalance capacity are installed, it may be possible to obtain the desired reduced voltage by having arrangements made so that either the positive or negative circuit breaker of the converter may be left open and the converter neutral connected to the bus on which the breaker is left open. This will give voltages about one-half as large as given in Table I for primary starting.

If the stations are operated with several busses at different voltages, it is of course necessary to take this into account when starting up the station. It might be found advisable to have the arrangements made for closing the d-c. circuit breakers on several of the converters at the same time by means of special control connections, so that the first machines which are connected to the system may be connected simultaneously, thus avoiding the possibility of having one or two trip off on overload.

The exact procedure to be followed in adapting the substations in any particular system to this method of reestablishing the Edison service can only be arrived at after making a thorough analysis of the problem.

While it is thought that the method of reenergizing outlined in detail will be found to be satisfactory, it is not the intention to give the impression that it is in general better than the other methods mentioned, as it is thoroughly realized that under certain conditions the method discussed would not be applicable at all. Which one of the methods of reestablishing service is made use of should be determined by making a comprehensive study of the situation.

Tooth Frequency Losses in Rotating Machines

BY THOMAS SPOONER

Westinghouse Electric & Mfg. Co.

Data are presented showing the hysteresis and eddy current losses due to minor displaced hysteresis loops superimposed on major loops of various amplitudes.

In all cases the amplitude of the minor loops is made proportional to the displacement which approximates the conditions which occur in machines. These data are applied to the case of the induction motor having a sine wave field distribution and a sample case worked out showing that the hysteresis losses in the teeth due to the tooth pulsations may be of the same order of magnitude as the losses due to the fundamental frequency. The eddy current losses in thin sheets due to the high-frequency pulsations are in general negligible but may be quite appreciable in the pole faces where the sheets are thicker. There are of course other losses due to tooth pulsations such as eddy current and circulating losses in the copper, etc., but these are beyond the scope of the present investigation.

Introduction

The calculation of core losses in rotating machines is based very largely on empirical data derived from tests of complete machines. That this procedure is followed is due to two chief causes.

1. The large magnitude and uncertainty of the illegitimate losses due to imperfections in manufacture such as bending strains in the sheet, burrs, filing of slots, etc.

2. Lack of sufficient fundamental data and design formulas.

The illegitimate losses are so large and variable at times that the designer feels that any refinement in calculations is a waste of time. This feeling on the part of the designer is largely responsible for the lack of design data since the designer has not demanded it.

When small changes only are made from standard designs the empirical data are fairly satisfactory, but when radically new designs are worked out, it frequently happens that the calculated losses are far from the true values. When a machine fails to meet the calculated losses, the designer should know whether the fault is due to his design or to poor shop practise. Of the various factors at present not subject to calculation which go to make up iron losses in rotating machines, those due to high-frequency tooth pulsations seemed to be the most important. In some cases it seems probable that these tooth pulsations may be responsible for more than 50 per cent of the total iron losses.

A few years ago a paper[1] was presented before the A. I. E. E. giving some data on displaced hysteresis loops. These data were rather meager and not very directly applicable to rotating machines since the authors considered only the displacement factor or the increase in hysteresis loss of a displaced minor loop occurring at the tip of a major loop over that of a symmetrical loop of the same amplitude. Referring to Fig. 1, the displacement factor is the ratio of the area of loop No. 1 to that of a small symmetrical loop at the center having the same B amplitude.

Recently the author has undertaken a further investigation along the same line in an effort to obtain results which are more nearly applicable to the conditions which exist in rotating machines.

1. *The Effect of Displaced Magnetic Pulsations on the Hystereiss Loss of Sheet Steel.* L. W. Chubb and Thomas Spooner, Transactions A. I. E. E., 1915, Vol. XXXIV, page 2671.

Experimental Procedure

Test Samples. The experimental data were obtained on ring punchings from three kinds of material. The samples were 4 7/16 in. (11.27 cm.) outside diameter and 3 7/16 in. (8.73 cm.) inside diameter. These samples were mill annealed but not reannealed after punching. They weighed about one pound apiece and had the following characteristics:

Sample	Gage Inches	Silicon Content
A	0.028	2.25%
B	0.012	1.0 %
C	0.017	1.0 %

These materials are all standard electrical sheet. The silicon contents are only approximate.

Test Methods. These samples were wound with suitable primary and secondary windings and tested

TABLE I

Loop	B max = 10,000 Lower tip	Upper tip	B max = 15,000 Lower tip	Upper tip	B max = 17,000 Lower tip	Upper tip
1	8000	10000	12000	15000	13600	17000
2	4800	6000	8000	10000	9600	12000
3	2400	3000	4000	5000	4800	6000
4	−3000	−2400	−5000	−4000	−6000	−4800
5	−6000	−4800	−10000	−5000	−12000	−9600

ballistically, using a modification of a ring testing apparatus[2] previously described. The main hysteresis loops were measured by determining each point in-

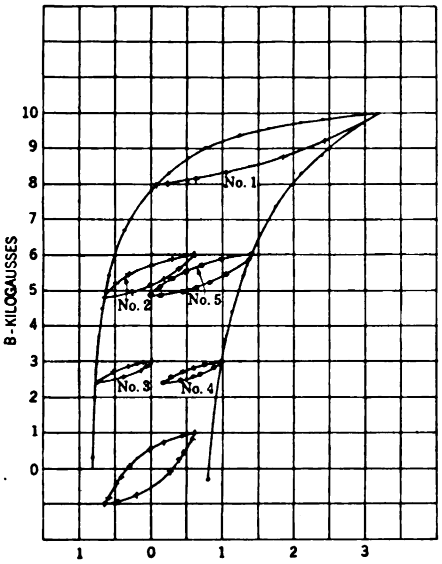


Fig. 1—Sample *C*

B_{max} equals 10 kilogausses. Amplitude of displaced loops equals 20 per cent of displacement.

dependently with reference to the tip value. The displaced loops were, for convenience, measured by means of the step by step method. The samples were placed in oil to avoid heating. Two primary and two secondary coils were used one set of a few turns and the other of many, thus making it possible to obtain high sensitivity for both low and high main loops. For testing high induction major loops, a sensitive ammeter was automatically switched into circuit when reading low values.

The procedure for determining a displaced minor loop was as follows:

The sample was brought into a cyclic condition for the major loop by reversing the magnetizing current

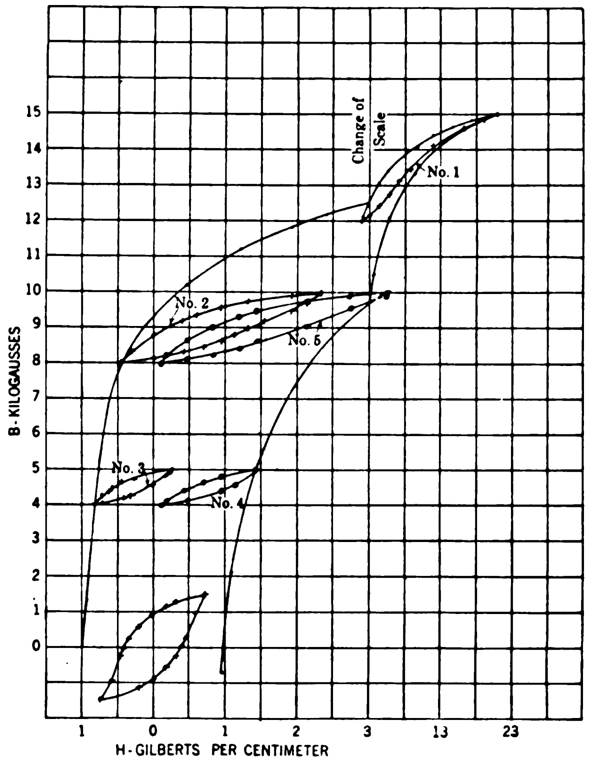


Fig. 2—Sample *C*

B_{max} equals 15 kilogausses. Amplitude of displaced loops equals 20 per cent of displacement.

a number of times. Then starting from the tip of the major loop, the induction was reduced to the lower tip of the minor loop in one step. From this point, step by step, we ascended to the upper tip of the displaced loop and then descended to the induction of the lower tip.

In all cases the amplitude of each displaced loop was 20 per cent of the displacement of the tip farthest from the zero line of induction. For each sample three maximum inductions for major loops were taken, namely, B = 10, 15 and 17 kilogausses. Table I gives the upper and lower tip values for all loops.

Test Results

A typical set of hysteresis loops for sample *C* are given by Figs. 1, 2 and 3 for maximum inductions of 10, 15 and 17 kilogausses respectively. The inductions were calculated from the net section as determined by the weight of the samples and an assumed specific gravity of 7.7. The losses for the major loops expressed in ergs per cu. cm. per cycle are given in Table II.

2. "Rapid Testing of Magnetic Materials," T. Spooner, *Electrical World*, Vol. 74, July 5, 1919.

The losses for the displaced loops are given by Table III.

These losses expressed in per cent of the major loop losses are given by Figs. 4, 5 and 6.

It will be noted that with the different major loops there happened to be associated a number of minor loops having the same amplitude and displacement. The losses for these loops have been collected in Table IV for convenient comparison.

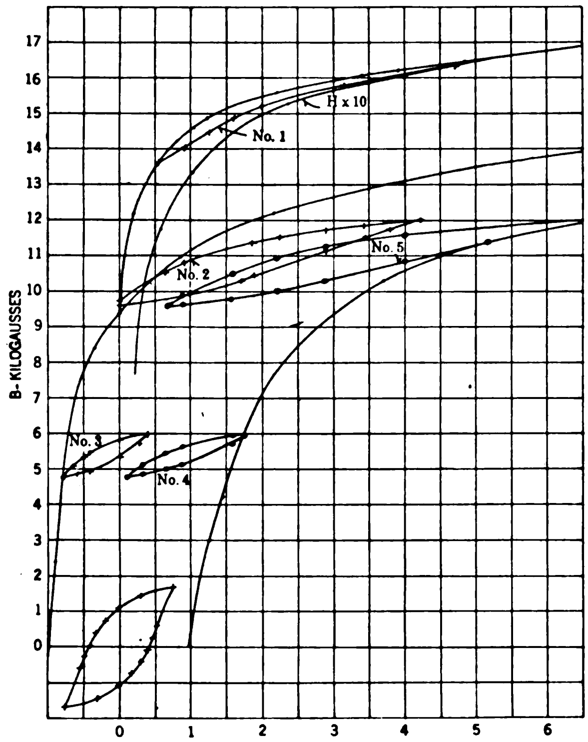


FIG. 3—SAMPLE *C*

B_{max} equals 17 kilogausses. Amplitude of displaced loops equals 20 per cent of displacement.

For comparison with previous work the displacement factors have been calculated for the No. 1 loops. Results are given in Table V.

TABLE II

B max	Sample A	Sample B	Sample C
10000	3110	2960	2780
15000	6000	7700	6252
17000	7930	10400	9010

Fig. 7 shows the effect of repeated reversals of magnetizing force on the hysteresis loss between the same maximum and minimum values of *H*. This particular curve is for a No. 4 displaced loop superimposed on a major loop of $B = 17$ kilogausses for the *B* ring and shows the difference between the first and fourth cycles for the same *H* amplitude.

CALCULATED RESULTS

Hysteresis Loss. In order to apply these results to specific conditions such as the loss in the teeth of an induction motor, calculations were made from the data of the *C* sample, assuming a sine-wave field form. On this assumption, the reference tip of each minor loop will be proportional to the cosine of the angle of rotation in electrical degrees, assuming that B_{max} occurs at an angle of 0 deg. Suppose now we assume 18 teeth per pole. This will correspond to a minor loop at each 10 electrical degrees. Now, if we multiply the cosine of the angle by B_{max}, this will give us the reference tip for each displaced loop corresponding to the abscissa of Fig. 6. Next we take the corresponding percentage losses from this curve for each 10 deg. over a range of 180 deg., add the percentages, multiply by two and we have the percentage hysteresis losses due to the displaced loops for a complete cycle. If this be done for various numbers of teeth it will be found that the losses are directly proportional to the number of teeth. We have then:

Table III

Loop	Ring No. A	Ring No. B	Ring No. C
Losses (Ergs) *B* max = 10			
1	147	148	162
2	33	37	37
3	8.6	10.5	10.5
4	8.0	9.8	9.8
5	46	49	47
6	147	148	162
B max = 15			
1	407	650	550
2	152	141	140
3	26	29	26
4	24	36	29.5
5	190	179	148
6	407	650	550
B max = 17			
1	790	980	890
2	222	237	218
3	39	47	41
4	46.5	52.3	48.5
5	237	340	292
6	790	980	890

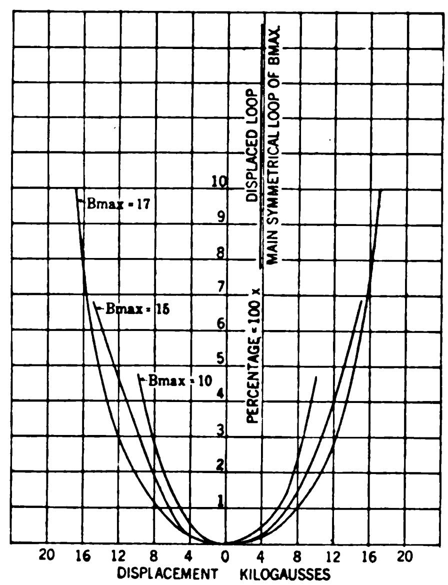


FIG. 4

$$P = K\,T \tag{1}$$

where P = the loss of the minor loops in per cent of the loss of the major loop,
K = a constant
T = teeth per pair of poles.

If the percentage loss as calculated above be divided by the number of teeth per pair of poles the results will be K for the given B_m and for an assumed pulsating induction of 20 per cent. In order to obtain K for other

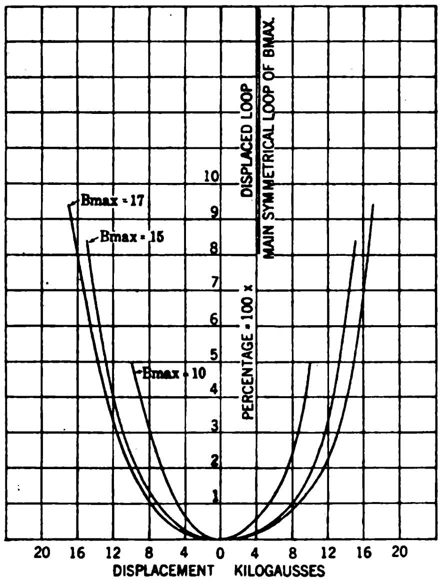


FIG. 5

pulsating amplitudes we assume that the hysteresis loss for the displaced loops is proportional to 1.6 power of the amplitude of the displaced loop. That this assumption is not far from the truth is shown by previous investigation[3] in which the exponent varied from about 1.6 to 1.5 for the larger displacements. Table VI gives these constants.

$P = K T$

P = percentage loss
K = constant
T = teeth per pair of poles

K 10/30 = K for B_m = 10 and ampl. of 30 per cent.

These results are plotted in Fig. 8. The total hysteresis loss due to the displaced loops may be calculated from the following formula:

$$W_{hd} = C K T f \qquad (2)$$

where W_{hd} = watts per kilogram for a given B_m.
C hysteresis loss in watts per kilogram per cycle for a given B_m, due to the major hysteresis loops.
K = a constant
T = teeth per pair of poles.
f = fundamental cycles per second.

C may be determined by the ordinary Epstein test for the particular material considered. The eddy current losses must of course be deducted from the Epstein test value and the result divided by the frequency. Or C may be calculated directly from the area of hysteresis loop as determined ballistically. In case of the induction motor, T must be reduced in proportion to the slip, namely,

$$T = T_1 \times \frac{\text{Rotor Speed}}{\text{Syn. Speed}}$$

where T_1 is the actual number of teeth.

This applies both to the rotor and stator. If the number of teeth in the rotor and stator are different the pulsating losses in the rotor teeth are based on the number of teeth in the stator, and the losses in the stator on the number of teeth in the rotor.

The same formula may be used for calculating the losses with the inductions expressed in lines per square inch, and the losses in watts per pound or per cubic inch. In this case the three values of B_m for the curve of Fig. 8 expressed in lines per square inch will be 64.5, 86.8 and 98.3 corresponding to 10, 15 and 17 kilogausses respectively. The only other change needed is to express C in term of watts per pound or watts per cubic inch as desired.

Eddy Losses. A formula for the corresponding eddy current losses in the iron may be calculated as follows;

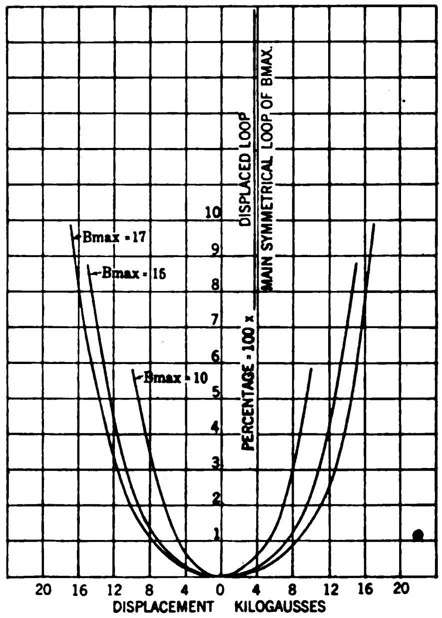


FIG. 6—SAMPLE C—1 PER CENT SILICON—0.0172-IN. GAGE
Displacement is based on tip farthest from O B. Amplitude of displaced loop is 20 per cent of displacement.

assuming as before a sine-wave field form. Let us assume an eddy current loss of 1.0 watt per kilogram at B_m = 10 kilogausses and 60 cycles. This is a fair value for 17-mil 1 per cent silicon steel. Assuming that the eddy loss is proportional to the square of the frequency and the square of the induction we get,

$$W_e = 2.78 \times 10^{-6} \times B^2 \times f^2 \qquad (3)$$

where W_e is in watts per kilogram
B is in kilogausses
f is in cycles per second

Let us assume 36 teeth per pair of poles (one tooth every 10 electrical degrees) a fundamental frequency

3. Ibid.

of 60 cycles, a B_m of 10 kilogausses and an amplitude of 20 per cent for the displaced loop. The harmonic frequency would then be 60 × 36 or 2160 cycles per second and the amplitude of the maximum displaced loop would then be 2 kilogausses corresponding to a B of one kilogauss. Applying these data to formula (3) and dividing by the harmonic frequency, we get

TABLE IV
Comparison of displaced loops having same amplitude.

Sample	Amplitude	B_{max}	Loop No.	W_h
A	2	10	1	147
"	"	15	2	152
"	"	"	5	190
B	"	10	1	148
"	"	15	2	141
"	"	"	5	179
C	"	10	1	162
"	"	15	2	140
"	"	"	5	148
A	1.2	10	2	33
"	"	"	5	46
"	"	17	3	39
"	"	"	4	46.5
B	"	10	2	37
"	"	"	5	49
"	"	17	3	47
"	"	"	4	52.3
C	"	10	2	37
"	"	"	5	47
"	"	17	3	41
"	"	"	4	48.5

the eddy loss for the maximum loop at 0 deg. This procedure is repeated for every 10 deg. the induction being numerically equal to the cosine of the angle. The eddy losses are then summed up for the complete cycle. The result for the eddy losses due to the displaced loops for the particular conditions specified in watts per kilogram is 1.08. Assuming that the

TABLE V
Displacement factors for rings A, B and C for 20 per cent loops.

Ring	$B = 10$	$B = 15$	$B = 17$
A	2.45	2.35	5.16
B	1.81	4.08	4.87
C	2.24	3.90	5.17

Amplitude of minor symmetrical and displaced loops are as follows:

B*	Ampl.	Mean Displ.
10	2	9
15	3	13.5
17	3.4	15.3

*B is the upper tip of the displaced loop.

eddy losses vary as the square law we may write the formula directly.

$W_{ed} = K\,(T \times t \times f \times P \times B_m)^2$ (4)

W_{ed} is expressed in watts per kilogram
T = teeth per pair of poles (with suitable corrections for slip as explained above.
t = thickness of laminations in inches
f = fundamental frequency in cycles per second
P = per cent amplitude of displaced loop
B_m = maximum induction in kilogausses per net section

By supplying 1.08 as calculated above in (4)
$K = 1.96 \times 10^{-9}$ which is an average constant for 17-mil 1 per cent silicon steel.

Of course, if the losses are to be expressed in units such as watts per cubic inch or the induction, thickness, etc., in other units the constant may be readily con-

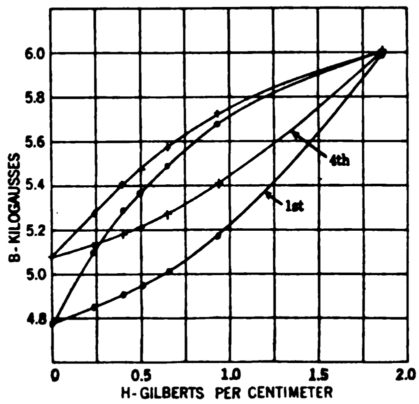


FIG. 7—SAMPLE B

Showing effect of repeated reversals of magnetizing force between the same H limits.
W_h equals 52.3 (1st) ergs per cu. cm. per cycle.
W_h equals 32.3 (4th) ergs per cu. cm. per cycle.

$$32.3\left(\frac{1.2}{0.92}\right)^{1.6} \text{ equals } 49.5 \text{ (cf. 52.3)}$$

verted to take care of these units. It must of course be changed for other materials, and will be approximately inversely proportional to the resistivity of the material. The assumed losses were for sheet having a

TABLE VI

$B_m = 10$	$B_m = 15$	$B_m = 17$
K 10/30 = 4.96	K 15/30 = 7.04	K 17/30 = 7.56
K 10/25 = 3.69	K 15/25 = 5.25	K 17/25 = 5.63
K 10/20 = 2.59	K 15/20 = 3.68	K 17/20 = 3.95
K 10/15 = 1.63	K 15/15 = 2.33	K 17/15 = 2.49
K 10/10 = 0.85	K 15/10 = 1.22	K 17/10 = 1.30
K 10/5 = 0.28	K 15/5 = 0.40	K 17/5 = 0.43

resistivity of about 23 microhms per centimeter cube. The resistivity for other silicon alloys may be calculated by the following formula:

$$R = a + k\,S \qquad (5)$$

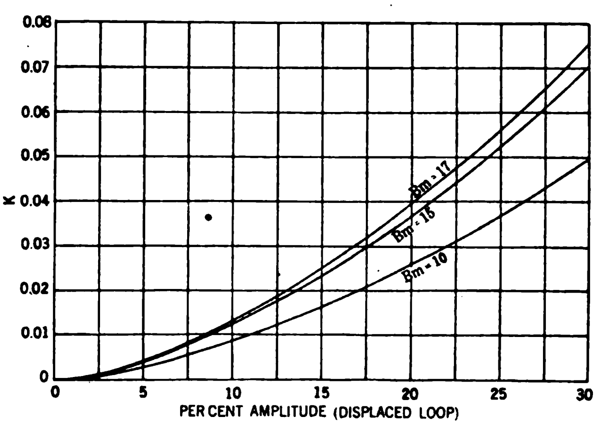


FIG. 8—FACTOR K FOR FORMULA (2) CALCULATED FROM DATA OF C SAMPLE

where R = The resistance in microhms per cm.[3]
a = 12
k = 11
S = silicon content in per cent.

As an example of the use of the above mentioned formulas and curves calculations will be made for the following conditions:

Material	= 1 per cent silicon steel
Thickness	= 17 mils
f	= 60 cycles
B_m	= 17 kilogausses
T	= 40 teeth per pair of poles
P	= 20 per cent (amplitude of displaced loops)

Let us also assume that the iron has a total loss due to the fundamental frequency of 12 watts per kilogram at $B_m = 17$ kilogausses which is a reasonable figure.

The eddy losses will then be from (3).

$W_e = 2.78 \times 10^{-6} \times 17^2 \times 60 = 2.90$ watts per kilogram.

The hysteresis losses is $12 - 2.9 = 9.1$ at 60 cycles and 0.152 per cycle.

The hysteresis loss due to the displaced loops is now from (2)

$W_{hd} = 0.152 \times 0.0398 \times 40 \times 60 = 14.5.$

The eddy losses due to the tooth pulsation are as follows from (4)

$W_{ed} = 1.96 \times 10^{-9} (40 \times 0.017 \times 60 \times 20 \times 17)^2 = 0.38.$ Therefore W (total) $= 12 + 14.5 + 0.38 = 26.9$ watts per kilogram.

Discussion of Results

The displaced hysteresis loops as determined by the method used do not altogether represent the conditions which exist in machines due primarily to the fact that these loops were obtained independently by starting each time from the tip of the major loop and going directly to the lower tip of the minor loops. In machines the minor loops follow one another with increasing or decreasing amplitude with a considerable number of minor loops superimposed on each major loop. It might be thought that this would have a demagnetizing effect tending to decrease the area of the loops. As a matter of fact there is such a tendency but it is small. Fig. 7 shows a fourth loop compared to a first loop, the former having a considerably smaller area than the latter. This is due chiefly to the fact that the fourth loop under the conditions of test has a smaller B amplitude although the H amplitude is the same. When the area of the fourth loop was multiplied by the 1.6 power of the difference in B amplitudes, the result nearly equals the areas of the No. 1 loop. In machines the conditions would correspond more nearly to definite B limits than definite H limits. In the A. I. E. E. paper referred to above, Fig. 24, page 2689, gives results on a first and tenth displaced loop taken between definite B limits of 7 and 9 kilogausses. The area of the first loop is 2.58 and of the tenth 2.32. We believe therefore that these different conditions will not introduce large errors. It is possible also that the minor loops may have an appreciable effect on the area of the major loops. If such an effect exists, it would be to decrease the losses due to the fundamental frequency.

It will be noted from Table IV and from Figs. 1 2 and 3 that the area of the displaced loops in general increases not only with the B displacement but with the H displacement also. In other words the No. 4 loop is usually larger than the No. 3 loop and the No. 5 loop larger than the No. 2. It will be noted that the percentage curves Figs. 4, 5 and 6 are nearly alike although the three samples are quite different in gage, chemical composition and losses. Therefore no large errors would probably be introduced by using these curves or the K curves of Fig. 8 for any class of electrical sheet having a silicon contents of not much over 2 per cent.

In order to calculate losses at high inductions, it is probably not feasible to obtain loops accurately at much higher values ballistically. We believe, however, that the percentage losses will not increase very much beyond those given for $B_m = 17$. Let us refer to Fig. 3 showing the data for $B_m = 17$. At higher values of B the ascending and descending branches apparently nearly coincide. It is possible that a displaced loop at very high B would have little or no area. This should certainly be true if the loop limits were entirely above the saturation point. At very high B_m values then the percentage curves might even decrease. There seems to be a tendency in this direction, at least for the B and C samples. We believe therefore that no serious errors would be introduced by using the K curves for $B = 17$ kilogausses (98.3 lines per square inch) for all higher inductions.

For other kinds of material the only other factor necessary to consider for approximate results is the specific normal hysteresis loss per cycle at the given B_m or C of formula (2).

Of course, when the designer comes to apply these results to a specific problem there will be a number of uncertain factors such as amplitude, percentage of tooth pulsation at various parts of the tooth, flux density of the teeth, etc. Moreover, these results have been put into usable form only for a sine wave field form and would have to be recalculated in a different way for other field forms. In addition to tooth pulsation losses, it is believed that the results may be used for the calculation of pole face losses as well by proper manipulation.

Finally these data should be applicable where the whole flux pulsates due to high-frequency reluctance variations in the air gap.

Future Work

In order to apply these data, a more accurate knowledge of the magnitude, distribution and depth of penetration of these tooth pulsation seems essential. An estimate of the magnitude of these pulsations is made very difficult due to the damping action of the eddy and circulating currents in the iron and copper.

In conclusion I wish to acknowledge the assistance of Mr. G. H. Keulegan who did most of the experimental work.

Skin Effect in Large Stranded Conductors at Low Frequencies

BY W. I. MIDDLETON and E. W. DAVIS

Both of the Simplex Wire & Cable Co.

THE resistance of metallic conductors is higher for alternating currents than for direct currents, due to the so-called "skin-effect." With alternating currents, the distribution is not uniform throughout the cross-section, there being a tendency for the current to concentrate towards the outside of the conductor, thus causing an increase of resistance and consequent increase of power loss.

Fig. 1 shows the power loss per 1000 feet in a 1,000,000-cir. mil cable; curve A gives the loss when the cable

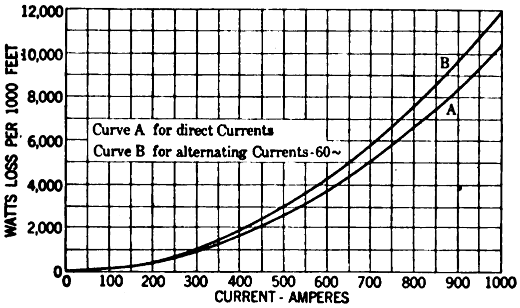


FIG. 1—WATTS LOSS PER 1000 FT.

Copper wire, 1,000,000 cir. mils

Resistance: D-c.—0.01034 ohms per 1000 ft.

A-c.—0.01186 " " " "

is carrying direct currents; curve B gives the loss when the cable is carrying 60-cycle alternating currents. The larger losses shown by the curve B are caused by the higher resistance of the cable to alternating currents than to direct currents.

The current density throughout the cross-section of any large size conductor carrying alternating currents is similar to those shown by the curves in Fig. 2. The density at the outside of the conductor is assumed as unity.

The increased demand for large size conductors carrying heavy alternating currents has aroused the interest of engineers to the importance and magnitude of the increase of resistance due to skin effect.

Much experimental work has been done to determine the skin effect in small conductors at radio and telephonic frequencies, and the results are of inestimable value to the radio and telephone engineer. Very little experimental work has been done at the low frequencies of 25 and 60 cycles, although many theoretical and approximate formulas are available.

There are three common formulas for skin effect which we shall designate as A, B and C respectively.

Formula A is found in the Appendix to Sir Wm. Thomson's Inaugural Address to the Institution of Electrical Engineers in 1889.

σ = specific resistance, c. g. s. units
= 1610 for copper

a = radius of wire

$R(S) = \dfrac{\sigma l}{\pi a^2}$ = resistance of any length l of a wire with steady currents

$R(N)$ = effective ohmic resistance of the same length l with alternate current of N periods per second

$$q = \left(2\pi\sqrt{\frac{2N}{\sigma}}\right) r$$

where $r = a$

$$\frac{R(N)}{R(S)} = \frac{1}{2}\, q \times \frac{ber.q\ bei'.q - bei.q\ ber'.q}{(ber'q)^2 + (bei'q)^2}$$

By ber and bei, denote two functions defined as follows:

$$ber.q = 1 - \frac{q^4}{2^2\,4^2} + \frac{q^8}{2^2\,4^2\,6^2\,8^2} \ldots \text{etc.}$$

$$bei.q = \frac{q^2}{2^2} - \frac{q^6}{2^2\,4^2\,6^2} + \frac{q^{10}}{2^2\,4^2\,6^2\,7^2\,10^2} \ldots\ldots \text{etc.}$$

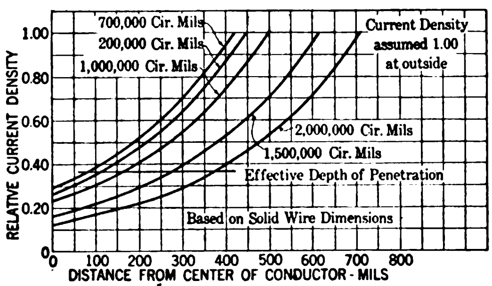


FIG. 2

The accents denote differential coefficients.

$$ber'.q = -\frac{4q^3}{2^2\,4^2} + \frac{8q^7}{2^2\,4^2\,6^2\,8^2} \ldots \text{etc.}$$

$$bei'.q = \frac{2q}{2^2} - \frac{6q^5}{2^2\,4^2\,6^2} + \frac{10q^9}{2^2\,4^2\,6^2\,8^2\,10^2} \ldots \text{etc.}$$

The following table of numerical results has been calculated using the above formula:

TABLE I

Values of q, $b\,e\,r\;q$, $b\,e\,i\;q$, etc., for

THOMSON'S FORMULA FOR SKIN EFFECT.

q	$b\,e\,r\;q$	$b\,e\,i'\;q$	$b\,e\,r\;q$	$b\,e\,i'\;q$	$\dfrac{b\,e\,i'\,b\,e\,r - b\,e\,r'\,b\,e\,i}{(b\,e\,r')^2 + (b\,e\,i')^2}$	$1/2\,q \times \dfrac{b\,e\,i'\,b\,e\,r - b\,e\,r'\,b\,e\,i}{(b\,e\,r') + (b\,e\,i')^2}$
0	1.000	0.0000	0.0000	0.0000	∞	1.0000
0.5	0.999	0.0625	−0.0078	0.24992	4.0000	1.0000
1.0	0.9844	0.2496	−0.062446	0.499947	2.00014	1.0001
1.5	0.9211	0.5576	−0.210011	0.730251	1.3678	1.0258
2.0	0.7517	0.9723	−0.4931	0.9170	1.0805	1.0805
2.5	0.3999	1.4571	−0.9436	0.9983	0.9398	1.1747
3.0	−0.2214	1.9376	−1.5698	0.8805	0.8787	1.3180
3.5	−1.1936	2.2833	−2.3361	0.4353	0.8526	1.4920
4.0	−2.5634	2.2927	−3.1347	−0.4911	0.8389	1.6778
4.5	−4.2991	1.6859	−3.7537	−2.0526	0.8279	1.8628
5.0	−6.2301	0.1160	−3.8442	−4.3538	0.8172	2.0430
5.5	−7.9735	−2.7902	−2.9070	−7.3729	0.8069	2.2190
6.0	−8.8584	−7.3348	−0.2931	−10.8462	0.7979	2.3937
8.0	20.9739	−35.0167	38.2944	−7.6615	0.7739	3.0956
10.0	138.8405	56.3704	51.373	135.23	0.7588	3.7940
15.0	−2969.79	−2952.33	−86.648	−4089.2	0.7431	5.5732
20.0	47583.7	11500.8	24325.1	41491.5	0.7325	7.3250

Formula B. In "Absolute Measurements in Electricity and Mangetism" by A. Gray, Vol. II, Part I, the following statement is made regarding effective resistance:

"The effective resistance is the same as the resistance which a surface stratum of the conductor of thickness

$$\frac{1}{a} = \frac{1}{\sqrt{2\,\pi\,\mu\,K\,\eta}}$$

would offer to a steady current."

$\frac{1}{a}$ = thickness in centimeters

μ = permeability of conductor material

η = frequency — cycles per second

K = constant depending on conductor material

= 0.00384 for copper

By this formula, the thickness of the surface stratum of a copper conductor carrying 25-cycle current is 1.29 cm. or 508 mils; for 60-cycle current it is 0.835 cm. or 329 mils. This "thickness of the surface stratum" may be referred to as the "effective depth of penetration" of the current

Formula C is published by D. B. Rushmore in the TRANSACTIONS of the A. I. E. E., 1912, Vol. XXXI, Part I, page 262.

C_s = skin effect ratio

d = diameter of conductor—inches

f = frequency

R = resistance to direct currents

R_1 = resistance to alternating currents

$R_1 = C_s R$

$$C_s = \frac{1 + \sqrt{1 + \left(\frac{K}{\sigma}\right)^2}}{2}$$

$$\left(\frac{K}{6}\right) = 0.0105\,d^2 f \text{ for copper}$$

Table II shows the skin effect factors for 1,000,000-cir. mil and 2,000,000-cir. mil copper cables as calculated by the three formulas given.

TABLE II

Skin effect factors—1,000,000-cir. mil and 2,000,000-cir. mil cables at 60 cycles

Size cir. mils	Outside Dia. inches	Formula A	Formula B	Formula C
1,000,000	1.157	1.176	1.24	1.155
2,000,000	1.625	1.588	1.545	1.471

In large size conductors which are to be used for alternating currents, it is common practise to substitute a rope or fiber core, for the center strands, which have a very low current density. With the increased demand for such conductors, the lack of standardization in the size of the rope used becomes very apparent. It is not uncommon to have specifications for conductors of the same cross-section to be operated on the same type of systems, calling for rope cores more than 50 per cent different in diameter. Specifications written a few years back call for rope cores 18/32 in. to 28/32 in. for various sizes of conductors, while specifications written more recently require cores of 14/32 in. to 41/32 in. diameter. All of these specifications are in common use.

The wide variations in specifications and the apparent lack of experimental data led the authors to conduct the tests described below.

The size of rope core used for any conductor is dependent upon the skin effect ratio of that conductor and should be of such size as to make the effective resistance of the conductor for the working frequency sensibly the same as its resistance to direct currents.

Formulas A, B, C are theoretical or approximate formulas that may be used for skin effect calculation in the design of a rope-core cable. Formula A is a theoretical mathematical formula, the theory of which

is based upon the assumption of solid conductors. It is too complicated and the numerical substitutions are too tedious to be of great value to the average engineer. There are many simplified and approximate formulas which are claimed to be modifications of Thomson's formulas, and which may be found in many electrical text-books and handbooks. The use of these formulas, however, gives widely varying results when applied to stranded conductors. Formula *C* is an approximate formula, but it checks the theoretical formula better than most such formulas.

Formula *B* appeals to the authors as the simplest of the three as it gives a certain definite effective penetration of alternating currents from the surface of a conductor. For copper conductors, this penetration

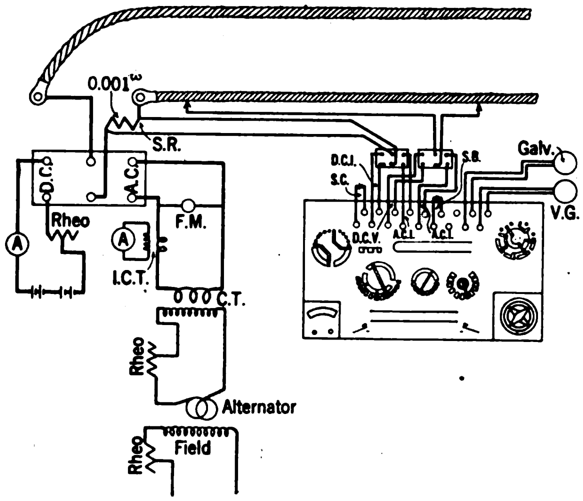


FIG. 3

A	= ammeter	*A. C. V.*	= a-c. volts
F. M.	= frequency meter	*C. T.*	= current transformer
S. C.	= standard cell	*S. B.*	= 8-volt storage battery
D. C. I.	= d-c. current	*V. G.*	= vibrating galvanometer
D. C. V.	= d-c. volts	*I. C. T.*	= instrument current transformer
A. C. I.	= a-c. current	*S. R.*	= standard resistance

depends only upon the frequency. The numerical value of the penetration is easily remembered, being 329 mils for 60-cycle current and 508 mils for 25-cycle current.

The following tests were made to obtain experimental data concerning the effective resistance of large-size stranded conductors to alternating currents of the low frequencies of 25 and 60 cycles. Particular attention was paid to the calculated effective depths of penetration of the current, in order to determine how far and with what modifications formula *B* can be applied to stranded conductors.

The skin effect was determined by measuring the current in the cables, the voltage drop across a known length of cable, and the phase angle between this current and voltage. A Drysdale alternating and continuous-current potentiometer was used. The current was determined by the use of a current transformer, and checked by voltage measurements across a standard 0.001-ohm resistance.

A coil attached to the cable would have a voltage induced between its terminals in phase with the current in the cable. The phase angle between this voltage and the voltage across a known length of cable is the phase angle between the current and voltage of the cable. This method was used to determine the phase angles between currents and voltages in these tests.

Current for the direct-current tests was supplied by a set of storage batteries; the current for the 25-cycle tests was supplied by a 25-kv-a. single-phase generator; the current for the 60-cycle tests was supplied by a commercial city circuit.

The cable samples were looped around the floor. Tests showed that the size of the loop had little or no effect upon the effective resistance. A diagram of the connections is shown in Fig. 3.

The cable samples tested were usually fifty feet in length, potentiometer measurements being made between two potential points fifteen feet apart.

Tests at 25 and 60 cycles were made on 700,000-cir. mil, 800,000-cir. mil, 1,000,000-cir. mil 1,500,000-cir. mil, and 2,000,000-cir. mil cables, dimensions of which are shown in Table III.

TABLE III

Cable dimensions—25-cycle and 60-cycle tests

Nominal Size	Actual cir. mils	Stranding	Outside Dia.	Pitch Dia.
700,000	698,389	61–.107	0.963	0.856
800,000	798,734	61–#9	1.030	0.912
1,000,000	1,007,049	61–#8	1.156	1.028
1,500,000	1,502,319	91–#8	1.414	1.286
2,000,000	2,100,000	127–#8	1.670	1.542

TABLE IV

Results of tests at 25 cycles

Size cir. mils	Current amperes	A-C. Resistance 1000 ft. (ohms)	D-C. Resistance 1000 ft. (ohms)	A-C/D-C. ratio	Effective current penetration mils
700,000	162	0.01481	0.01483	1.00	To center
	296	0.01475		0.998	of
	400	0.01480		1.00	Conductor
800,000	215	0.01358	0.01360	1.000	To center
	496	0.01350		0.993	of
	605	0.01352		0.994	Conductor
	686	0.01350		0.993	
1,000,000	340	0.01076	0.01034	1.040	501
	440	0.01081		1.047	
	560	0.01089		1.052	
	680	0.01080		1.046	
1,500,000	172	0.007315	0.007084	1.031	493
	420	0.007600		1.071	
	530	0.007700		1.088	
	700	0.007750		1.095	
2,100,000	340	0.00509	0.00452	1.125	
	480	0.00500		1.109	518
	610	0.00510		1.129	

Average penetration from above results—504 mils
Calculated penetration from Gray's formula—508 mils

Table IV gives the results of the tests made at 25 cycles. Various current values were used for each

conductor in order to determine if there was any effect of current density upon the effective resistance.

In calculating the effective current penetration, the pitch diameter of the conductor, rather than the outside diameter, is used. Tests made at 500 cycles for the specific purpose of checking Gray's formula as applied to stranded conductors, indicate that the current penetration should be calculated from the pitch diameter of the outer layer of strands. The results of the 500-cycle tests are shown later.

TABLE V

Results of tests at 60 cycles

Size cir. mils	Current amperes	A-C. Resistance 1000 ft. (ohms)	D-C. Resistance 1000 ft. (ohms)	A-C./D-C. Ratio	Effective current penetration mils
700,000	191	0.01525	0.01483	1.028	356
	212	0.01528		1.030	
	291	0.01526		1.029	
800,000	183	0.01493	0.01360	1.099	
	260	0.01470		1.082	326
	330	0.01490		1.096	
	420	0.01481		1.090	
1,000,000	200	0.01195	0.01034	1.159	
	292	0.01170		1.131	315
	376	0.01170		1.131	
	516	0.01202		1.162	
	750	0.01198		1.159	
	830	0.01182		1.142	
1,500,000	179	0.00901	0.007084	1.271	
	420	0.00913		1.289	311
	495	0.00891		1.260	
	640	0.00902		1.275	
2,100,000	480	0.00639	0.00452	1.415	336
	860	0.00628		1.390	
	950	0.00636		1.412	

Average penetration from above results—329 mils
Calculated penetration from Gray's formula—329 mils

Table V gives the results of test made at 60 cycles. As in the case of the 25-cycle tests, different current densities have no effect upon the effective resistance. The largest deviation between the average effective current penetration for any size and that of 329 mils calculated by Gray's formula, is for 700,000 cir. mils, a deviation of 8.2 per cent. This large deviation is probably due to the slightly fluctuating frequency during these particular tests.

TABLE VI

Cable dimensions—500-cycle tests

Stranding	Actual cir. mils	Outside Dia.	Pitch Dia.
7 strds—No. 5 B & S	231,700	0.546	0.363
19 strds—No. 9	248,710	0.572	0.460
37 strds—No. 12	241,600	0.567	0.495
61 strds—24 of No. 14 18 of No. 14 12 of 0.066 7 of 0.066	255,600	0.578	0.514

In order to determine experimentally whether skin effect calculations, based on the pitch diameter of a stranded conductor, are correct, 500-cycle tests were made on four specially designed cables of the dimensions shown in Table VI. An attempt was made to have four cables of approximately the same diameter, the same copper circular mils, but laid up with widely different stranding. The result was four cables having very different pitch diameters.

At 500 cycles, skin effect is much more pronounced than at 25 cycles or 60 cycles, and therefore much more conclusive results would be expected. If the skin effect of a conductor were a function of the copper circular mils or the outside diameter, the ratio of resistances for these four cables should be approximately the same.

TABLE VII

Results of tests made at 500 cycles

Size	Current	A-C. Resistance 1000 ft. (ohms)	D-C. Resistance 1000 ft. (ohms)	A-C./D-C. ratio	Effective current penetration mils
7strands of No.5	59.2	0.0504	0.0457	1.104	
231,700 cir. mils	65.2	0.0498		1.091	113
	70.6	0.0490		1.072	
19 strds of No.9	80.4	0.0556	0.0434	1.280	
	83.12	0.0565		1.300	110
248,710 cir. mils	73.76	0.0573		1.320	
37strds of No.12	78.75	0.0563	0.0442	1.285	
	71.0	0.0588		1.331	110
241,600 cir. mils	67.7	0.0578		1.308	
61 strands					
24 of No. 14					
18 of No. 14	73.9	0.0608	0.04385	1.385	
12 of 0.066	81.4	0.0594		1.352	115
7 of 0.066	87.3	0.0588		1.340	
255,600 cir. mils					

Average penetration from above results–112 mils
Calculated penetration from Gray's formula–113 mils

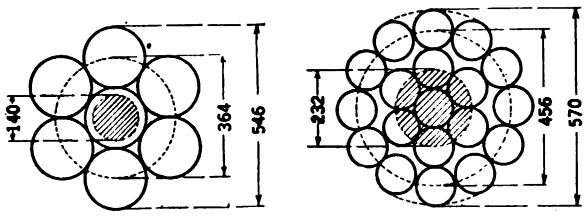
Table VII shows the results of the tests made at 500 cycles. A glance at the resistance ratios shows that they do not follow as a function of the outside diameter or of the circular mils. The effective current penetration, calculated from the pitch diameter, however, checks very closely with the theoretical value of 113 mils for 500 cycles, calculated by Gray's formula. This would indicate that for stranded conductors, skin effect calculations should be based on the pitch diameter of the outer layer of strands.

Fig. 4 shows a cross-section of the four special cables used for the 500-cycle tests. The shaded sections are called "useless copper," that is, the copper inside the effective depth of current penetration.

The seven-strand cable has considerably less useless copper than the other three, we believe because of its much smaller pitch diameter. The 61-strand cable has the largest pitch diameter and the largest amount of useless copper. This would indicate that for concentric stranding, the larger the size strand for any given circular mileage the less the skin effect.

Table VIII gives the stranding and dimensions of three extra flexible, rope-stranded, 2,000,000-cir. mil

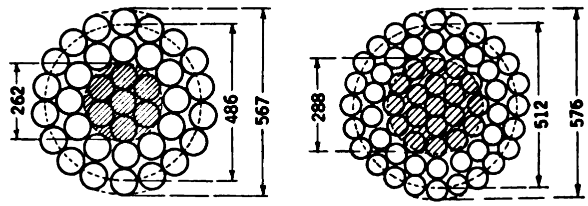
cables. Tests were made on these cables in order to determine whether they followed the same formula for skin effect as the concentric stranded cables.



231,700 cir. mils
7 strands, No. 5 B. & S.
Useless copper—19,200 cir. mils

248,710 cir. mils
19 strands, No. 9 B. & S.
Useless copper—57,410 cir. mils

Frequency = 500~



241,600 cir. mils
37 strands, No.12 B. & S.
Useless copper—57,000 cir. mils

255,600 cir. mils
19 strands.0.066 42 strands, No.14B.&S.
Useless copper—66,100 cir. mils

FIG. 4

Fig. 5 shows diagrammatically the method used to make measurements on these cables.

P-T is a direct-current potentiometer so wound that it is suitable for 60-cycle alternating currents. *M* is

TABLE VIII

Dimensions—Extra flexible 2,000,000 cir. mils

Stranding	Actual cir. mils	Outside dia.	Pitch dia.
37—(7 × 7-0335)	2,034,190	2.110	1.809
61—(7 × 7-0265)	2,098,280	2.146	1.907
127—(7-0485)	2,090,930	1.892	1.745

a mutual inductance, the primary of which is connected in series with the potentiometer as shown. The current in the inductance primary, and in the potentiometer circuits, are in phase; any potentiometer voltage

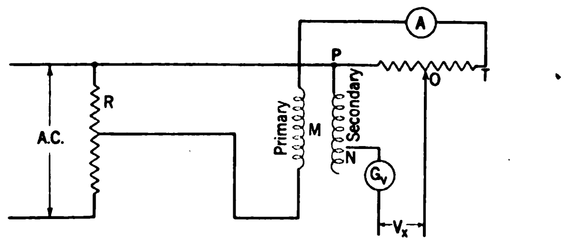


FIG. 5

A = ammeter
$P\ O\ T$ = d-c. potentiometer
M = mutual inductance
V_x = unknown voltage
G_v = vibration galvanometer
R = rheostat

PO, is in phase with this current; any induced voltage in the inductance secondary is 90 deg. out of phase with this current. By keeping the current through the inductance potentiometer circuit constant at rated current for the potentiometer, the voltage *PO*, is read directly, and the voltage *P Z* may be readily calculated.

$$V_{pz} = 2\pi f L \times I$$
f = frequency
I = potentiometer current
L = inductance

The total voltage $Z\,O = \sqrt{(V_{pz})^2 + (V_{po})^2}$

This method of measurement is much simpler to set up and operate than the a-c. potentiometer; it does not require any difficult phase-splitting and does not require any complicated or unusual apparatus.

The same measurements on the cables were made as when the Drysdale alternating- and continuous-current potentiometer was used, and the same methods used to calculate results.

Table IX shows the results at 25 cycles and Table X at 60 cycles.

TABLE IX

Results of tests on rope-strand cables at 25 cycles

Stranding	Current amperes	A-C. Resistance 1000 ft. (ohms)	D-C. Resistance 1000 ft. (ohms)	A-C/D-C. Ratio	Aver. approx. effective current penetration mils
37—(7 ×7-0335)	582	0.00613	0.00525	1.168	
	720	0.00618		1.178	
	826	0.00600		1.142	549
	970	0.00611		1.162	
	1027	0.00611		1.162	
61—(7 ×7-0265)	588	0.00710	0.00570	1.245	
	724	0.00740		1.298	425
	793	0.00724		1.270	
	877	0.00738		1.295	
127—(7-0485)	600	0.00605	0.00520	1.162	
	738	0.00631		1.212	473
	793	0.00630		1.211	
	887	0.00653		1.256	
	1025	0.00616		1.182	

Average penetration from above tests—482 mils
Average penetration from Gray's formula—509 mils

TABLE X

Results of tests on rope-strand cables at 60 cycles

Stranding	Current amperes	A-C. Resistance 1000 ft. (ohms)	D-C. Resistance 1000 ft. (ohms)	A-C./D-C. Ratio	Aver. approx. effective current penetration mils
37—(7 ×7-0335)	797	0.00721	0.00525	1.373	
	916	0.00731		1.392	351
	1026	0.00726		1.384	
61—(7 ×7-0265)	678	0.00905	0.00570	1.588	
	812	0.00912		1.600	326
	910	0.00894		1.569	
	1051	0.00898		1.575	
127—(7-0485)	641	0.00743	0.00520	1.429	
	768	0.00735		1.413	338
	860	0.00721		1.386	
	976	0.00752		1.445	
	1050	0.00766		1.472	
	1140	0.00752		1.445	

Average penetration from above tests—338 mils
Average penetration from Gray's formula—329 mils

From these tests it is apparent that the skin effect of rope-stranded cables can be calculated to a fair degree of accuracy by assuming the same current penetration as for solid or concentric stranded conductor; and that the current penetration should be calculated from the pitch diameter of the outside layer of bunches of strands.

Conclusions

1. The effective resistance of a conductor to alternating current depends upon the amount of conducting material in a surface stratum of approximately 508 mils thickness for 25 cycles and approximately 329 mils for 60 cycles. The thickness of this "surface stratum" is referred to as the "effective depth of current penetration."

2. Effective depth of current penetration is the same for stranded conductors as for solid conductors. For stranded conductors, the depth should be calculated from the pitch diameter of the outer layer of strands.

3. Skin effect of *stranded* conductors is not a direct function of the total copper circular mils or of the outside diameter.

4. Skin effect in any conductor is independent of the current.

5. Current penetration varies as the square root of the current frequency.

6. The larger the size of strand used for any conductor, the less the skin effect and the less the amount of useless copper. For practical purposes, the size of strand should not be so large as to interfere with the flexibility of the cable.

The writers believe that the subject is of sufficient importance to warrant a very thorough investigation, that all experimental data available should be published, and that the matter should receive the attention of the Institute in its Standards.

The authors are indebted to the electrical engineering departments of Harvard University and Massachisetts Institute of Technology for the use of special apparatus and for suggestions in this work.

APPENDIX

Rope-Core Cables

Table XI shows the range of rope-core diameters in use at the present time for various sizes of conductors.

TABLE XI

Size Cond. cir. mils	Dia. Rope Core inches
2,000,000	28/32 to 41/32
1,750,000	25/32 to 39/32
1,500,000	22/32 to 34/32
1,250,000	18/32 to 27/32
1,000,000	15/32 to 19/32
800,000	11/32 to 16/32
700,000	9/32 to 14/32

The smaller the over-all diameter of a copper conductor, the less expensive the finished cable. Thus it is to the advantage of the purchaser when considering the first cost of an installation, to specify the lower limit diameters of rope cores. On the other hand, if the rope core is not sufficiently large, the cable will contain a considerable amount of copper which is not being effectively used.

Applying Gray's formula to stranded cables by calculating the effective depth of current penetration from the pitch diameter of the outer layer of strands, the ideal strand for any rope-core cable may be readily determined.

Let N = number of layers of strands

Z = effective depth of current penetration for the working frequency

d = diameter of ideal strand

$$d = \frac{Z}{N - 0.5}$$

d will be in the same units that are used to express the depth of penetration.

TABLE XII

Ideal strands for rope-core cables

Frequency	Layers of strands over rope core		
	3	4	5
25		145 mils	113 mils
60	131.5 mils	94 mils	

Table XII shows the ideal strands to be used for rope-core cables at frequencies of 25 and 60 cycles.

TABLE XIII

Dimensions of rope-core cables—25 cycles
Using ideal strand

Size cond.	Rope core diam.	Strand	Outside diameter	Actual cir. mils
1,250,000	0.140	98 —0.1135	1.27	1,250,000
1,500,000	0.320	117—0.1135	1.45	1,490,000
1,750,000	0.400	83—0.145	1.56	1,748,000
2,000,000	0.547	95—0.145	1.71	2,000,000

TABLE XIV

Dimensions of rope-core cables—60 cycles
Using ideal strand

Size cond.	Rope Core	Strand	Outside diam.	Actual cir. mils
700,000	0.225	80—0.094	0.98	706,000
800,000	0.324	91—0.094	1.08	803,000
1,000,000	0.504	113—0.094	1.26	998,000
1,250,000	0.665	73—0.1315	1.46	1,261,000
1,500,000	0.834	87—0.1315	1.62	1,505,000
1,750,000	1.041	101—0.1315	1.83	1,749,000
2,000,000	1.249	116—0.1315	2.04	2,010,000

Tables XIII and XIV show the dimensions of ropes, outside diameters, and actual cir. mils for rope-core cables using the ideal strands listed in Table XII. In actual practise these cables should be modified so that commercial sizes of rope and ordinary strands can be used.

Tables XV and XVI show dimensions of rope-core cables, using B. & S. sizes for strands. The diameters of cores are those found for commercial ropes. The method of stranding (*i. e.*, using B. & S. sizes) is in accordance with the latest N. E. Code rulings.

TABLE XV

Rope-core cables for 25 cycles—Using B & S sizes for strands

Nominal cir. mils	Rope core		Stranding	Actual cir. mils	Per Cent deviation from nominal cir. mils	Outside diam.
	Theoretical	Actual				
1,500,000	19/64 +	10/32	72 strds #7	1,500,000	0	1.46
1,750,000	27/64 +	14/32	84 " #7	1,750,000	0	1.59
2,000,000	20/32 +	20/32	98 " #7	2,040,000	+2	1.78

TABLE XVI

Rope-core cable for 60 cycles—Using B & S sizes for strands

Nominal cir. mils	Rope core		Stranding	Actual cir. mils	Per Cent deviation from nominal cir. mils	Outside diam.
	Theoretical	Actual				
700,000	8/32	9/32	84 strds #11	692,000	−1.14	1.01
800,000	11/32 +	12/32	96 " #11	790,000	−1.25	1.10
1,000,000	29/64 +	15/32	60 " #8	991,000	−1.00	1.24
1,250,000	43/64 −	22/32	75 " #8	1,238,000	−0.97	1.46
1,500,000	28/32	28/32	90 " #8	1,485,000	−1.01	1.66
1,750,000	65/64	32/32	61 " #8 29 " #6	1,745,000	−0.28	1.84
2,000,000	73/64	36/32	66 " #8 34 " #6	1,970,000	−1.52	1.96

AMERICAN ELECTRICAL MACHINERY FOR AUSTRALIA

The State Electricity Commission of Victoria for some months past has been engaged in arranging for the execution of the various portions of the State electricity project. Trade Commissioner A. W. Ferrin states in *Commerce Reports* that tenders from the United States have recently closed for that portion of the electrical installation comprised under the general heading of "transformers and switch gear." This includes the whole of the apparatus which transforms the electric energy from the voltage of generation at Morwell up to the voltage of transmission; also the switch gear and the electrical mechanism for operating the apparatus and all the control gear. It also includes the step-down transformers, synchronous condensers and switch gear of the Newport terminal station, as well as apparatus for a number of metropolitan substations. The tender for the whole apparatus by an American company was much less than the lowest possible combination of English tenders. The terms of delivery offered by this company was also more satisfactory than that offered by any other tender, and the State Electricity Commission therefore recommended to the Government that the tender be accepted. The commission has also recommended the acceptance of an American company's tender for the supply of conductors for the main transmission line from Morwell to Newport. The line will comprise six separate wires, making the total length of the conductors about 700 miles. The alternative materials open for consideration were copper and aluminum-coated steel. The tenders received showed a heavy advantage in favor of steel, which has the further advantage of greater strength than copper, thus permitting of the employment of longer spans and therefore of fewer steel towers, insulators, etc. It is estimated that by the employment of steel-aluminum instead of copper conductors a total saving upon the whole outlay on the transmission line of about £100,000 will be effected.

NEW ELECTRIC PLANT AT NANKING

Owing to the inability of the existing electric plant at Nanking to furnish sufficient current to meet the needs of the city and its suburbs, a new plant has recently been added. The plant complete, exclusive of the site, cost the equivalent of $125,000 American currency. The generator is an American made turbo-generator producing a 2300-volt, three-phase and 60-cycle current with direct-connected exciter. The boiler-feed pump and supply pumps are of American manufacture. The feed-water heater is also American, as is the 4-inch by 5-inch vertical steam engine used for the stoker drive. The building for the new plant was erected by the Nanking Electric Light Co. under the supervision and according to the plan of an American-educated Chinese engineer. The installing of the machinery was done by an American engineering firm.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. MEETINGS

CHANGE OF POLICY

The following resolutions relating to Institute meetings were adopted at a meeting of the Board of Directors held May 20, 1921, upon recommendation of the Committee on Coordination of Institute Activities:

RESOLVED: (1) To place all regular monthly meetings of the Institute and Sections throughout the country on the same basis; that is to make them all Section meetings.

(2) To continue the three general meeting of the Institute each year, namely, the Annual, Pacific Coast and Midwinter Conventions, and the annual business meeting in May, with such other additional meetings as may be authorized from time to time by the Board of Directors.

(3) To hold the Directors' meetings in New York City, excepting when the Board, for special reasons, decides to meet elsewhere.

RESOLVED further: That the policy outlined above be adopted with the understanding that the regional vice-presidents, in accordance with the recommendations of the Development Committee, will visit the Sections in their respective territories and otherwise assist in coordinating their activities; also that the Meetings and Papers Committee at headquarters will cooperate with the respective Sections and render such aid as may be feasible in developing desirable programs for Section meetings.

At a meeting of the Directors held August 16, 1921, the following resolution was adopted:

RESOLVED: That, beginning with the calendar year 1922, in addition to the annual meeting there shall be four general meetings of the Institute, including the Annual Convention.

The above resolutions have been referred to the Meetings and Papers Committee and the Committee on Coordination of Institute Activities for guidance in forming plans for coming meetings; and it is expected that these committees will formulate detailed recommendations which will receive consideration by the Directors in October.

A. I. E. E. NOVEMBER MEETING

JOINT SESSION WITH THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

The 372d meeting of the Institute will be held in the Engineering Societies Building on Thursday, November 17, 1921. The meeting will consist of an afternoon and an evening session.

The afternoon session will be a joint session with the Society of Naval Architects and Marine Engineers, forming a part of the annual meeting of that society. Two papers will be presented at this session as follows:

Electric Auxiliaries, by E. D. Dickinson, Marine department of the General Electric Co.

Electric Propulsion, by W. E. Thau, Commerical Engineer of the Westinghouse Electric and Mfg. Co.

The evening session will be devoted to a lecture on *World Communication*, by Alfred N. Goldsmith, Professor of Electrical Engineering, City College of New York.

A. I. E. E. DIRECTORS MEETING

AUGUST 16, 1921

The first meeting of the Board of Directors of the American Institute of Electrical Engineers for the administrative year beginning August 1, 1921, was held at Institute headquarters, New York, on Tuesday, August 16.

There were present: President William McClellan, Philadelphia; Past Presidents, A. W. Berresford, Milwaukee and Calvert Townley, New York; Vice-Presidents N. W. Storer, Pittsburgh, F. W. Springer, Minneapolis, W. A. Hall, Boston, J. C. Parker, Ann Arbor, Mich., W. A. Del Mar, Yonkers, N. Y.; Managers, G. Faccioli, Pittsfield, Mass., Frank D. Newbury and A. G. Pierce, Pittsburgh, E. B. Craft and Harlan A. Pratt, New York, R. B. Williamson, Milwaukee; Treasurer, George A. Hamilton, Elizabeth, N. J.; Secretary, F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $16,746.40 was ratified.

A report was presented of a meeting of the Board of Examiners held August 8, 1921. Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications: 34 Students were ordered enrolled; 106 applicants were elected to the grade of Associate; 20 applicants were elected to the grade of Member; 15 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

President McClellan announced the appointments of committees for the administrative year beginning August 1, 1921. (These committees are listed elsewhere in this issue.)

In accordance with the by-laws of the Edison Medal Committee, the Board confirmed the appointment by the President of Messrs. B. A. Behrend, John H. Finney and Charles S. Ruffner to the Edison Medal Committee for a term of five years, and elected from its own membership Messrs. A. W. Berresford, L. F. Morehouse and R. B. Williamson, to serve upon the Edison Medal Committee for a term of two years.

Local Honorary Secretaries Guido Semenza, for Italy and Charles leMaistre, for England, were reappointed for a term of two years ending July 31, 1923.

The following representatives of the Institute upon the American Engineering Council, of the Federated American Engineering Societies, whose terms expire December 31, 1921, were reappointed for a term of two years ending December 31, 1923: Messrs. H. W. Buck, W. A. Layman, Wm. McClellan, L. F. Morehouse, L. T. Robinson, C. S. Ruffner.

President McClellan made the recommendation that meetings of the Board of Directors be held bi-monthly in future, and in New York City in accordance with the action taken by the Board at its May meeting; the Executive Committee to take

action on all matters that need attention between meetings of the Board. The following resolution was adopted:

RESOLVED, that starting with October 1921, the regular meetings of the Board of Directors shall be held in New York City, at approximate intervals of two months, and arranged so as not to prevent the attendance of members of the Board at meetings of the Institute.

The following minute was adopted as a memorial to Francis Bacon Crocker, Past President of the Institute:

With Francis Bacon Crocker, whose death occurred on July 9, 1921, there passed one of the ablest electrical engineers of the world. Interested in the art and science of electrical engineering from early childhood, he served the profession as few men have been permitted to serve. As a pioneer designer of commercially successful motors, as a founder and director of the School of Electrical Engineering at Columbia University and in a similar capacity with the Crocker-Wheeler Company, as an advocate of world standardization in the electrical field—in all the numerous activities with which he was connected, Dr. Crocker's genius is indelibly recorded.

It is, therefore, with a sense of extraordinary loss to the engineering profession that the Board of Directors of the American Institute of Electrical Engineers records the death of one who served as President for the year 1897-1898 and as chairman and member of many committees, decrees that this minute be entered in the Institute records as an expression of its appreciation of his personality, career and attainments.

In addition to these actions other matters relating to important activities and the general policy of the Institute were discussed; reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

AMERICAN ENGINEERING COUNCIL

MEETING OF EXECUTIVE BOARD

Washington, September 30

The Executive Board of American Engineering Council of the Federated American Engineering Societies will meet in Washington, D. C., on September 30. The most important business of the meeting will be the election of a president to succeed Herbert Hoover, who resigned after becoming Secretary of Commerce. Nominations to fill this office were ordered at the last Board meeting, so that they could be reported at the September meeting. Other matters bearing on the management of Council, its membership, and the work of its committees will be taken care of at this meeting. The Board will give special attention to the plans for the Engineering Assembly (see below), the extension of employment service, and the question of licensing and registration of engineers.

ENGINEERING ASSEMBLY

An Engineering Assembly, authorized by a special vote of the Executive Board at the Philadelphia meeting, will be held in conjunction with the annual meeting of American Engineering Council, next January. It is planned to make the assembly a three-day session, one day to be given to special meetings of the executive boards of member organizations and committees of the American Engineering Council, one day to the sessions of the American Engineering Council, and at least one day to the discussion of some special topic such as elimination of waste, licensing of engineers. the national department of public works or some other subject of equal importance to the engineering profession.

An Engineering Assembly Committee has been appointed with A. P. Davis of Washington, Chairman, and with the following members: Philip N. Moore of St. Louis, L. P. Alford of New York City, John C. Hoyt of Washington, and F. A. Vaughn of Milwaukee. This committee will work out detailed plans for the assembly.

NEW EDITION OF N. E. L. A. REPORTS

The demand for copies of the reports of the Prime Movers Committee and of the Overhead Systems Committee of the National Electric Light Association exhausted the original edition and both reports have been reprinted in full.

The report of the Prime Movers Committee covers, turbines, condensing equipment, boilers and auxiliaries, stokers, economizers, power station auxiliaries, coal and ash handling, piping, boiler and turbine room instruments, buildings and foundations and power station sites, oil and gas engines, and various fuels. It contains 360 pp. 8 x 11 in., illustrated, $3.50 to members, $7.00 to non-members.

The report of the Overhead Systems Committee includes: transmission line construction, insulator maintenance and research, maintenance of live transmission lines, line construction materials, revision of wood pole specifications, use of concrete poles, lightning arrester practise, operation and maintenance of transformers, etc. It contains 204 pp. 8 x 11 in. illustrated, $2.00 to members, $4.00 to non-members.

E. M. F. ELECTRICAL YEAR BOOK

A new electrical reference book has just been published by the Electrical Trade Publishing Co., of Chicago, under the title of E. M. F. Electrical Year Book, which promises to make a very useful annual reference book of current information for the electrical industry. It comprises three leading features: Compilations of facts and figures about each branch of the industry, definitions of electrical and allied terms, and a classification of products made and used by the industry with listings of their producers. All topics are entered alphabetically, the entire text being arranged as in an encyclopedia or dictionary so that it is very easy to find any item desired.

All the editorial work on the book was done under the general direction of Frank H. Bernhard, who has been on the editorial staffs of various electrical publications. Most of the technical topics were prepared by a staff of some thirty contributing editors, including college professors, electrical engineers and other specialists in their respective lines.

The book contains about 1000 pages, 9 by 12 in., and is priced at $10.

PERSONAL MENTION

CHARLES F. SCOTT has been elected president of the Society for the Promotion of Engineering Education.

V. A. ZEHR, consulting engineer of Pekin, Ill., sailed August 4th for Europe to investigate a construction work near Prague, Bohemia.

A. C. CORNELL has become manager of the Denver Supply Distributing House of the Western Electric Company. He has been sales manager of the company in Denver.

A. TELFORD SMITH, formerly with the Winnipeg Electric Railway Company, Winnipeg, Man., is now located with the Sao Paulo Electric Company, Ltd., Sao Paulo, Brazil.

J. M. WAUCHOPE has accepted appointment as superintendent of the Walla Walla River Plant of the Pacific Power & Light Company, at Milton, Ore.

A. T. RUSTAD, formerly of the Cutler-Hammer Mfg. Company, Milwaukee, Wis., is now located as inspector with Murrie & Company, construction engineers, New York City.

WARD B. KINDY has left the Iowa State College, where he was instructor in the Electrical Engineering Department, to take up the same work in Leland Stanford Jr. University.

ROBERT LINDSAY, who has been vice-president and general manager of the Cleveland Electric Illuminating Company, was recently elected president of the company.

H. R. Eilertsen has left the Cutler-Hammer Mfg. Co., where he was employed as service engineer, and is located with R. Hoe & Co., New York City.

Arthur W. Swisher, who was a junior engineer with the General Electric Company, has taken a position with The Falls Equipment Company, Niagara Falls, N. Y.

Robert N. Nielsen has left Lockwood, Greene & Co., Chicago, and is at present with the F. E. Newbery Electric Company, Chicago.

C. A. Malone, formerly of the California-Oregon Power Company, has become assistant superintendent of The Hawaiian Electric Co., Ltd., Honolulu, Hawaii.

Fred E. Dace has left the Holt Mfg. Company, Peoria, Ill., to accept a position as instructor in electricity and mathematics at Bradley Polytechnic Institute, Peoria.

Carlyle D. Bidwell, formerly superintendent of construction with the J. I. Case Plow Work Company of Racine, Wis., is now located with the West Pullman Works of the International Harvester Company, Chicago, as plant engineer.

W. H. R. Burrows has severed his connections with the Wabi Iron Works, New Liskeard, Ont., Can., where he was general manager, to become general manager of the Canada Electric Castings Co., Ltd., Orillia, Can.

H. A. Maxfield has left the Westinghouse Electric & Mfg. Co., where he was employed in the research laboratory, and is working in the electrical engineering laboratory of the Worcester Polytechnic Institute, Worcester, Mass.

Wm. C. Murrell has recently resigned his instructorship at Cornell University, and has taken a position in the Distribution Department of the Public Service Electric Company in Newark, N. J.

John W. Carrothers has accepted a position as voltage operator with the Kansas City Power & Light Company. He was formerly employed in the office of Hans von Unwerth, consulting engineer, of Kansas City.

John P. Kobrock, until recently with the Central Union Telephone Company, Chicago, as general outside plant engineer, is now located with the Ohio Bell Telephone Company, in Cleveland.

Philip S. Biegler, associate editor of *Electrical World*, has resigned from this position to become associate professor of Electrical Engineering at the State College of Washington, Pullman, Wash.

T. L. Holmes, of the Western Electric Company, has been appointed manager of the Boston Telephone Distributing House of that company. He has been with the company since 1900, his last office being in Denver, Col.

H. H. Argabrite, until recently stores manager of the Western Electric Company in Denver, Col., has been appointed manager of the Denver Telephone Distributing House of that company.

J. A. Woidill, Jr., formerly electrical chief draftsman of Hog Island Shipyard, has recently become superintendent of the Atlantic County Electric Company and Enterprise Gas Company, Egg Harbor City, N. J.

William McClellan, President of the American Institute of Electrical Engineers, has recently been appointed, by Governor Sproul, a member of the Pennsylvania State Board for Licensing Engineers, under the law passed at the last session of the Pennsylvania Legislature.

Carl T. Mack has severed his connections with Henry L. Doherty and Company of New York, with whom he was engaged in patent research work in Washington, D. C., and is now employed by the patent law firm of Prentiss, Stone and Boyden, of Washington.

Clarence F. Backstrand is now associated with Howard F. Ross in the Riverside Electric Company, engineers and electrical contractors, Riverside, Cal. Mr. Backstrand was until recently assistant district manager of the Holton Power Company, El Centro, Cal.

R. A. Lundquist, of the U. S. Department of Commerce, has been appointed head of the Electrical Machinery Division in the Bureau of Foreign and Domestic Commerce, one of the new industrial divisions made possible by Congress through the export industries act. The government plans to secure the services of experts in these departments to specialize in the important export products.

Pedro Diaz, who for several years was at the head of the Foreign Department of the Western Machinery Company, of Los Angeles, Cal., has resigned his position in order to establish himself in the City of Mexico as manufacturers' representative. Mr. Diaz has been appointed exclusive agent in the Republic of Mexico for the Western Machinery Company and the Layne & Bowler Corporation, both of Los Angeles.

Paolo Tuccimei, of the National Association of Italian Engineers, has been appointed by that organization as "Official Correspondent of the National Association of Italian Engineers for the States of North America." This appointment follows Mr. Tuccimei's recent trip to the United States, during which he visited American technical societies, and established friendly and cordial relations with them on behalf of the Italian association. Mr. Tuccimei has since communicated with the American societies, and with his position as correspondent officially recognized will be able to do much towards maintaining friendly relations, and providing for exchange of ideas and programs between the organizations.

OBITUARY

Earl Edwin Sayre of Schenectady, N. Y., was accidentally killed with his wife in a motorcycle accident at Oneonta, N. Y., on July 8, 1921. Mr. Sayre, who recently joined the Institute, was born at Durand, Mich., in 1895. He received his technical education at the Michigan Agricultural College, from which he was graduated in 1918. In May 1919 he entered the employ of the testing department of the General Electric Company at Schenectady, remaining there until his death. During the World War he had been in active service overseas as Lieutenant in the Wireless Division of the Signal Corps.

William Wilson Lighthipe, of Brooklyn, N. Y., died August 7, 1921, in the Long Island Hospital. He had been ill for some time. Mr. Lighthipe was one of the foremost engineers of the Otis Elevator Company, and was known throughout the country as an expert on elevators. He started with the Sprague Elevator Company in 1898, upon his graduation from Columbia University, and in 1900 became general superintendent. In 1901 he was appointed assistant superintendent of the Otis Elevator Company, but a year later became associated with the Marine Engine & Machine Company, New York. Re-

turning in 1905 to the Otis Elevator Company, he remained there in various capacities until his death, at which time he was manager of the special sales division of the company. He was born in Vincentown, N. J., in 1876. An Associate of the INSTITUTE, Mr. Lighthipe also belonged to the American Society of Mechanical Engineers, the Sons of the American Revolution, and the American Canoe Club.

ROBERT TEN EYCK LOZIER, a Fellow of the Institute, died of pneumonia at the Post-Graduate Hospital, New York, August 21, 1921. Mr. Lozier had been active in the pioneer work of developing electrical power, having been associated with many of the leading electrical engineers at a time when the technical schools and colleges did not have established courses in electrical engineering. He was born in South Norwalk, Conn., in 1868, and entered the office of Thomas A. Edison at the age of fourteen. This practical work, together with mathematical studies, made up his technical training. Until 1895 he was associated with various electrical concerns, among them the Sprague Electric Motor and Dynamo Company, the Edison General Electric and the General Electric Companies. In 1895 he started into business as a member of Warren & Lozier, engineers, but the next year became associated with the Bullock Electric Company, remaining there for eight years. After that time his work was largely that of consulting engineer, in New York City.

During the war Mr. Lozier devoted considerable time to hydroplane construction at the League Island Navy Yard, Philadelphia. For a short time thereafter he was connected with the Standard Underground Cable Company, but early in 1920 resumed his practise as industrial consultant. At the time of his death he had offices in New York and Chicago.

Mr. Lozier had been a manager of the Institute, 1902-4, and had served on various committees. He was also a life member and past-president of the New York Electrical Society, and a member of the Engineers Club.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES JULY 1-31, 1921

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

THE AIRCRAFT HANDBOOK.

By Fred H. and Henry F. Colvin. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 415 pp., illus., 8 x 5 in., cloth. $4.00.

This work was first published in 1918 under the title, "The Aircraft Mechanics' Handbook," and was intended to meet the wartime need for a book for airplane mechanics. It has now been thoroughly revised and increased in scope to meet the needs occasioned by the development of commercial aviation.

The book is intended to give a good general knowledge of the principles involved in the design of airplanes and their motors without describing details and to show how both planes and motors are assembled, cared for and repaired.

CERAMICS.

By A. Malinovzsky. N. Y., D. Van Nostrand Co., 1921. 274 pp., tables, 7 x 4 in., cloth. $3.00.

The author of this small volume has attempted to write a condensed account of the silicate industries, including methods for silicate analysis and ceramic calculations, which will assist those engaged in the manufacture of clay products to solve the various mathematical problems that arise.

DIE DRAHTSEILBAHNEN.

By P. Stephan. Dritte auflage. Berlin, Julius Springer, 1921. 459 pp., illus., 9 x 6 in., cloth. 150M.

This work is presented as a complete treatise on wire ropeways. The first chapter is devoted to a historical account of their development. This is followed by a description of the various details, such as cables, towers, cars and buckets, landing stations and protective devices. Chapter three gives examples of the use of ropeways for transportation in mountainous lands, for river crossings and as conveyers in various industries, while chapter four presents the various types. Chapter six discusses the economic aspects of the subject and legislation. The closing chapter considers erection and operation.

THE ENGINEERS AND THE PRICE SYSTEM.

By Thorstein Veblen. N. Y., B. W. Huebsch, Inc., 1921. 169 pp., 8 x 5 in., cloth. $1.50.

Contents: On the Nature and Uses of Sabotage.—The Industrial System and the Captains of Industry.—The Captains of Finance and the Engineers.—On the Danger of a Revolutionary Overturn.—On the Circumstances which Make for a Change.—A Memorandum on a Practicable Soviet of Technicians.

This series of papers is reprinted from the "Dial" where they appeared during 1919. They discuss certain difficulties involved in the American industrial situation, and present the author's views concerning the way in which they will be solved.

HANDBOOK OF STANDARD DETAILS FOR ENGINEERS, DRAFTSMEN AND STUDENTS.

By Charles H. Hughes. N. Y. and Lond., D. Appleton and Co., 1921. 312 pp., tables, diagrs., 7 x 5 in., cloth. $6.00.

The book is a compilation, in a volume of convenient size, of drawings, tables and formulas of standard details. Included among these are fastenings of various kinds; shafting, clutches, collars, bearings, gearing and other parts of power transmission; pipes, tubes and fittings; rope and chain fittings; structural and miscellaneous details. Much of the material has been furnished by American machine-tool manufacturers and represents their practise. The work is intended for engineers, draftsmen, etc.

HANDBUCH DER INGENIEURWISSENSCHAFTEN.

Part I, Vol. 5. Tunnelbau, by Karl Brandau, Karl Imhof and Ernst Mackensen. 4th edition. Leipzig, Whilhelm Engelmann, 1921, 712 pp., plates, illus., 10 x 7 in., cloth. 56 M.

Part III, Vol. 6. Der Flussbau, by Franz Kreuter. 5th

edition. Leipzig, Wilhelm Engelmann, 1921. 724 pp., plates, illus., 10 x 7 in., cloth. 154 M.

The "Handbuch des Ingenieurwissenschaften" has long been favorably known as one of the most, if not the most ambitious attempts to publish an encyclopedia of civil engineering. Its thirty-seven volumes cover the field in a way suited for use as a reference book for practising engineers, giving concise accounts of modern theory and practise in their particular fields, accompanied by unusually extensive lists of references to the literature on their subjects.

Of the present volumes, that on Tunneling is a revision and enlargement of the edition issued by Dr. Mackensen in 1901, prepared by Dr. Brandau and Dr. Imhof before Dr. Brandau's death in 1917. A supplement by Dr. E. von Willman fills the gap occasioned by unavoidable delay in publication. The volume discusses tunneling in its applications to mining and railroads, covering design and construction, and illustrating the subject by numerous examples of actual construction.

Dr. Kreuter's treatise on river works covers the subject in a broad manner, including the construction of the various works by which natural water courses are regulated or utilized for transportation, for industrial purposes and in agriculture. Careful attention is given to the results of modern experimental work and the resulting scientific theories.

HANDBUCH DES WASSERBAUES.

By Hubert Engels. Zweite auflage. Leipzig, Wilhelm Engelmann, 1921. 2 vol., diagrs., 11 x 7 in.

The first edition of Engel's "Handbuch des Wasserbaues," published in 1914, was intended to meet the lack of a modern work covering the entire field of hydraulic engineering in a uniform manner that would give the reader a satisfactory account of present developments in the many special subjects which are included in that general term.

The work is divided into ten sections treating of the occurrence and movement of water, hydrology, river works, weirs, dams, and water power plants, protection of land, agricultural hydraulic works, navigation, ship locks, river canalization and ship canals, and harbors. Each of these is an extensive summary of modern theory and practise, accompanied by a list of "sources." The needs of the designer of hydraulic works, rather than those of the builder, have been kept in mind, and such topics as municipal water supplies, water purification and groundwaters have not been included.

The second edition has been revised and enlarged.

DIE HOCHSPANNUNGS-GLEICHSTROMASCHINE.

By A. Bolliger. Berlin, Julius Springer, 1921. 82 pp., diagrs, 10 x 6 in., paper. 18 M.

The development of the direct-current power system, so extensive in the earlier period, but less important since its replacement about 1890 by the alternating-current system, is now, the author believes, entering a new epoch where it will again be the more important, chiefly on account of the electrification of railroads. To use it economically, however, considerably higher working voltages must be attained.

The present monograph is devoted to a new machine for generating high-tension direct currents, which has been developed by the author and tested experimentally. This machine combines certain elements of a machine with mechanical commutation and one with rectifiers of the electrical valve type. The theory of the machine is given in detail, its construction described and the results of tests presented.

DER LICHSTROMBEGRIFF UND SEINE ANWENDUNGEN.

By N. A. Halbertsma. Berlin, M. Krayn, 1921. 62 pp., diagrs., 9 x 6 in., paper. 20 M.

The question discussed in this monograph is the comparative advantages of a system of photometric units based upon luminous intensity, in the customary manner, and one based upon light flux. The author concludes that the latter offers many theoretical and practical advantages, sufficient to justify its adoption.

PRINCIPLES OF RADIO COMMUNICATION.

By J. H. Morecroft, assisted by A. Pinto and W. A. Curry. N. Y., John Wiley & Sons., Inc.; Lond., Chapman & Hall, Ltd., 1921. 935 pp., illus., diagrs., 9 x 6 in., cloth. $7.50.

The opening chapters of this treatise discuss the ordinary laws of continuous and alternating-currents circuits, the transient conditions that continually occur in them and the peculiarities in the behavior of circuits when excited by the very high frequencies of radio work. Succeeding chapters cover each important phase of radio art; spark, telegraphy, vacuum tubes, continuous-wave telegraphy, radio telephony, antenna and radiation, wave meters and amplifiers. A considerable portion of the text is devoted to the theory and behavior of the thermionic three-electrode tube. The final chapter gives a short course of elementary experiments for laboratory use. The book is intended as a text-book for college students especially interested in its subject.

PROCEEDINGS OF THE PHILADELPHIA AND NATIONAL CONFERENCES OF THE CONSTRUCTION INDUSTRIES UNDER THE AUSPICES OF THE INDUSTRIAL RELATIONS COMMITTEE OF THE PHILADELPHIA CHAMBER OF COMMERCE AND THE NATIONAL FEDERATION OF CONSTRUCTION INDUSTRIES. Phila., 1921. 254 pp., 11 x 8 in., paper.

This volume presents the proceedings of the conferences held in February, 1921, by the Industrial Relations Committee of the Philadelphia Chamber of Commerce, and that held in March, 1921, by the National Federation of Construction Industries. At these conferences the construction situation was discussed by experienced men drawn from all the classes interested in construction, and an attempt was made to ascertain the economic and industrial readjustments which must be made before stable conditions can be attained.

THE SCIENTIFIC PAPERS OF BERTRAM HOPKINSON.

Collected and arranged by Sir J. Alfred Ewing and Sir Joseph Larmor. Cambridge, University Press, 1921. 480 pp., port., plates., diagrs., tables, 11 x 7 in., cloth. $20.00 (Gift of the Macmillan Co., N. Y.)

This memorial collection of Professor Hopkinson's writings includes all those that the editors consider of permanent importance, the omissions being either publications of transient interest or others adequately represented by papers included in the collection.

The papers here published may be grouped roughly under a few general heads. Two papers, written in conjunction with Sir R. A. Hadfield, describe researches on the magnetic properties of iron and its alloys. Another group of papers deals with the elastic properties of steel and other metals and with elastic hysteresis. A third group discusses various researches on gas engine phenomena, including heat flow and temperature distribution, and gaseous explosions. The remaining papers deal with the dynamics of explosions from a different point of view.

DIE STEUERUNGEN DER DAMPFMASCHINEN.

By Heinrich Dubbel. Zweite auflage. Berlin, Julius Springer 1921. 384 pp., illus., 9 x 6 in., cloth. 69 M.

This is a treatise on the theory and design of valve and reversing gears for reciprocating steam engines, for the use of designers. The discussion is confined chiefly to the modern forms that have been introduced to meet the demands of high steam pressures and increased speeds, and the competition of steam turbines and gas engines. Matter which is only of historical interest has been omitted, but full attention is given to gearing of the types which have proved best fitted to modern requirements. The discussion of reversing gears includes material on locomotives, rolling-mill and hoisting engines.

TRAITE DE BALISTIQUE EXTERIEURE.

By P. Charbonnier. Tome 1. Paris, Gauthier-Villars et Cie, 1921. 637 pp., diagrs., 10 x 6 in., paper. 75 fr.

This is the first of the six volumes in which it is proposed to publish Charbonnier's treatise on external ballistics to which the Poncelet prize was awarded by the French Institute in 1919. The author has planned, at this favorable time, a complete treatise, embracing everything relating to the science, methodically classified and treated in detail, suited to the needs of students of its theory and of practical artillerymen. His book therefore is a summary of our knowledge at the close of the great war.

The present volume, intended as an introduction to the subject, is divided into two parts. The first is a discussion of the three limiting cases of the ballistics problem, motion in a vacuum and rectilinear motion and vertical motion in a resisting medium. The second considers the general theorems of ballistics, and includes the general properties of atmospheric trajectories and the application of analysis to the ballistics problem.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Atlanta.—August 4, 1921, Assembly Hall, Carnegie Library. Election of officers as follows: Chairman, J. E. Mellett; Vice-Chairman, Geo. K. Selden, Jr.; Secretary-Treasurer, H. N. Pye; Executive Committee, Geo. A. Iler and C. E. Emerson. Mr. A. M. Schoen, delegate to the Annual Convention of the Institute at Salt Lake City, made an interesting report. Attendance 17.

Baltimore.—July 28, 1921, Field Day, Walbrook Athletic Club. The Section had as its guests the Baltimore Section of the A. S. M. E. At 7 o'clock a picnic supper was served and following the supper an informal meeting was held. Dr. Whitehead announced the result of the recent election and the new Chairman, Mr. D. Burnett, was installed. Dr. Whitehead gave an interesting report of the impressions which he gained at the recent A. I. E. E. Convention at Salt Lake City. Attendance 40.

Chicago.—June 20, 1921, Western Society of Engineers Rooms. Subject: "The Motion Picture's Secret Part in Winning the War." Speaker: Mr. John F. Strickler, of the Picture Service Bureau. Attendance 225.

Los Angeles.—July 5, 1921. Discussion of Institute Section affairs by past chairmen. President Berresford addressed the meeting and discussed Institute affairs in general. The meeting was preceded by a dinner in honor of President Berresford. Attendance 28.

Panama.—July 31, 1921, Cecelia Theatre. Five reels of motion pictures of the International Western Electric Company, were shown—two reels "Forging the Links of Fellowship," and three reels on modern road construction, maintenance, construction and repairs. Attendance 268.

Philadelphia.—June 17, 1921, Highland Park. Joint Philadelphia Sections of A. I. E. E., A. S. M. E. and I. E. S. In the afternoon a baseball game, tennis and golf were indulged in by teams chosen by the A. I. E. E. and the A. S. M. E.

ADDRESSES WANTED

A list of members whose mail has been returned by the postal authorities, is given below, together with the address as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—R. Coelho, 201 West 95th Street, New York, N. Y.
2.—W. F. Gantvoort, Kedongsarie, 84, Soerabaia, Java, Dutch East Indies.
3.—L. E. Given, 72 West Adams Street, Room 634, Chicago, Illinois.
4.—Conrad Jacobson, Hood River, Oregon.
5.—J. M. Keller, Box 121, Sparrows Point, Md.
6.—Harry P. Meyer, 327 East 61st Street, Los Angeles, Cal.
7.—Basil B. Pilcher, 691 East 230th Street, New York, N. Y.
8.—M. J. Pouillon, 95 Straps Street, Gent, Belgium.
9.—Albert G. Scholer, Dundee Lake, N. J.
10.—Martin Tracy, Tunnel Camp, Brittiania Mines, Howe Sound, B. C., Can.
11.—Frank N. Tucker, 551 East 40th Street, Chicago, Ill.
12.—J. F. Warris, U. S. S., S-3 Union Iron Works, San Francisco, Cal.
13.—Harry Wilson, J. G. White Engg. Corp., Marcus Hook, Pa.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y., the employment clearing house of the Societies constituting the Federated American Engineering Societies.

Notices for the JOURNAL are not acknowledged by personal letter, but they will usually appear in the next issue that goes to press.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to EMPLOYMENT SERVICE, as above.

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

MEN AVAILABLE

EXPERIMENTER, age 35; married. Fifteen years practical electrical and mechanical experience. Last ten years experimenting and developing. Have large fund of general electrical and mechanical knowledge. Particularly interested in automatic devices requiring electrical control. Position desired where opportunity for advancement could be expected as ability is proved. E-2915.

ELECTRICAL ENGINEER. Technical graduate; three years teaching experience in large engineering college, and four years experience in test and design departments of electrical manufacturer. Position wanted as assistant professor or instructor of electrical engineering in State University. Can teach either theory or in laboratory. Salary not less than $2500. Age 30. Available on 30 days notice. E-2916.

ELECTRICAL GRADUATE, Assoc. A. I. E. E., competent, trustworthy, age 34, six years hydroelectric operation. Desires position as chief operator in small plant or assistant in large. Employed but must get near high school. Prefer location where small farm may be secured near plant as I want to be permanent. E-2917.

SUPERINTENDENT or general foreman, seven years experience in substation and industrial plant installations and maintenance, technical trained. Assoc. A. I. E. E., age 27; married. Available immediately; location immaterial. Wish connection with a large company offering permanent employment with future opportunity for advancement. Good reference furnished. E-2918.

ELECTRICAL ENGINEER, graduate, age 34; married. Experienced in testing, installation, maintenance and design with a little teaching to pass it on to the other fellow. Would prefer

position as maintenance engineer with high grade industrial establishment that desires to have the electrical department run at the maximum of efficiency. E-2919.

ELECTRICAL ENGINEER, age 25; college graduate, three years experience in calculation of transmission lines layout for power and substations, desires position. Available on short notice. Speaks Spanish; willing to go anywhere. E-2920.

ENGINEER AND EXECUTIVE, thoroughly familiar with all phases of utility work, wishes to get in touch with corporation needing such services. Past experience includes eight years as executive engineer for one of the largest utility corporations during its entire development. Capable of working out consolidations. Understands operating and management problems. E-2921.

ELECTRICIAN, age 24; trade school graduate, with seven years experience in marine and maintenance, construction, shop and storage battery repairs, desires a position with opportunity for advancement. Assoc. A. I. E. E. E-2922.

SUPERINTENDENT or foreman of electrical construction and maintenance. Age 35; married. Ten years experience in factory and mines includes construction operation and maintenance. Three years experience in manufacture and testing of a-c. and d-c. motors and generators. Can handle men. Employed, but desire to change. Eastern States preferred. Assoc. A. I. E. E. E-2923.

ELECTRICAL ENGINEERING GRADUATE; age 32; married, desires position with power company where knowledge of operating characteristics of electrical equipment will be useful. Six years testing for one of the largest manufactures of electrical machinery. Four years inspecting machinery U. S. Navy. Associate A. I. E. E. Certified member A. E. E. E-2924.

ELECTRICAL ENGINEER, technical graduate; age 28. Nineteen months G. E. test. Two years industrial experience which includes installation and maintenance of motor-driven pumps, conveyers and hoists. Power plant and transmission line experience. Expert on electrical theory and calculations. Available immediately. References. E-2925.

ELECTRICAL ENGINEER; age 36. Fifteen years electrical and mechanical shop experience. Eight years in charge; used to modern methods. Good organizer and production getter. Desires position as supervisor of electrical or mechanical department or factory. Safety engineer or employment manager. Located in East; available immediately. Salary according to responsibilites. E-2926.

GRADUATE ENGINEER, E. E. degree; age 29; married; good personality; hard worker executive ability; former 1st. Lieut. Army, construction. One year experience with consulting engineer on hydroelectric construction; two years experience on other construction work; two years teaching experience. Assoc. A. I. E. E. Desires position as teacher or with engineering, manufacturing or light and power company. E-2927.

ELECTRICAL ENGINEER, age 32; married; graduate Virginia Polytechnic Institute, 1914. Assoc. A. I. E. E. Teaching experience in physics and mathematics; two years as officer in the Army; two and a half years sales engineer for Westinghouse E. and M. Co. Desires permanent position with engineering, manufacturing or light and power company, or as instructor in electrical engineering or mathematics. Location immaterial. Available after July 31. E-2928.

ELECTRICAL ENGINEER, available for foreign service. Expert on transformer design with broad experience on related problems of transmission, distribution and system protection. Graduate University of Wisconsin. Westinghouse apprentice. Member A. I. E. E. Age 28; married. Detailed experience furnished confidentially. E-2929.

MECHANICAL & POWER ENGINEER, technical graduate, B. S. and M. E., age 29; single. Seven years experience along broad lines, chemical manufacturing, machine shop, metallurgy, sugar engineering, industrial and power plant practise and operation, design, layout, calculations, steam, water, air, heating and distribution, investigation, etc. Has business and executive ability. Desires responsible position. E-2930.

SMALL MOTOR ENGINEER, technically trained. Six years practical experience on all forms of motor production. Expert on fan-motor and allied single-phase work. Would like position as foreman or assistant in test, assembly or other departments with manufacturing corporation. Assoc. A. I. E. E. Highest references. Age 27; married. E-2931.

ELECTRICAL ENGINEER, 1916 Columbia Univ., with executive ability and five years experience. Desires position as electrical engineer with a hydroelectric company or a firm of consulting engineers. Experience includes G. E. test, investigations and reports on power and transmission problems, use of calculating table for network studies, power rates. Salary $2500 to start. E-2932.

GRADUATE ELECTRICAL MECHANICAL ENGINEER, age 28; married. Four years experience in the design and manufacture of electrical machinery. For the last two years in a responsible position. Would like change where there is chance for advancement. E-2933.

POWER ENGINEER OR MECHANICAL SUPERINTENDENT with twenty years experience covering economical operation and maintenance of steam, electric and refrigeration plants, large buildings, manufacturing, pulp and paper mills. Executive ability. At present chief power engineer in charge of three plants. Available after September 1st. Salary commensurate with position. Location immaterial. E-2934.

ELECTRICAL ENGINEER, technical graduate. Broad practical engineering experience, capable and accustomed to handling engineering problems. Ten years experience in power plants and substation design, construction and operation, and electrical construction work. Desires responsible position with engineering, manufacturing or public utility company. Ohio or vicinity preferred. E-2935.

ELECTRICAL ENGINEER; age 24; single; Assoc. A. I. E. E.; technical graduate Mississippi A & M. One year graduate student course Westinghouse, one and one-half years test floor experience Westinghouse, one year Service engineer, office experience. Preferably central station power work. Location immaterial; available on short notice. E-2936.

ELECTRICAL ENGINEER with organized power plant design and construction corps and sales force wishes to represent manufacturers of electrical power plant equipment and supplies in New York territory with sole agency privileges. Have entree into best architect, engineer and contractor offices and large clientele. E-2937.

ELECTRICAL MECHANICAL ENGINEER technical graduate. One year G. E. test and practical electrician. Six years with power plant consulting engineer design, construction steam power plants, substations, industrial power, distribution, analysis and reports old plants. Capable handling all problems application steam and power in rubber, textile, paper and chemical plant. E-2938.

GRADUATE ELECTRICAL ENGINEER; age 30; married. Five years experience including G. E. test, central station test department instructor in radio division of air service and manager of small hydroelectric company. Desires position with hydroelectric company, central station company or firm of consulting engineers. Available on short notice. E-2939.

SALES ENGINEER, age 30; married; graduate electrical engineer with seven years experience storage batteries and welding, desires permanent connection with future rewarded by ability and effort. Available immediately. E-2940.

ELECTRICAL ENGINEER, 9 years central station experience, desires position as electrical engineer or superintendent; central station company, or industrial concern. University graduate, age 35; married. E-2941.

ELECTRICAL ENGINEER; age 34, married, technical graduate degree M. S., light and power industrial applications, installation, operation and maintenance, location Philadelphia, Pa. Would like interview. E-2942.

RECENT GRADUATE of M. I. T. with S. P. and S. M. in Electrical Engineering desires position with some industrial or firm of engineers. Has had 2 years technical teaching and 2 years industrial experience. At present employed as a junior management engineer. Location Eastern Coast. E-2943.

ELECTRICAL ENGINEER. Age 31. Married B. E. and E. E. degrees. Speaks Spanish. Nine years experience in the layout, ordering materials for, installation and operation, of over 200,000 h. p. in miscellaneous electrical equipment, both large and small. Good parallel mechanical experience. Proved organizing and executive ability. Now holding responsible position, but immediately available at a salary of $3600 a year. E-2944.

ENGINEER. Age 26. Desires position as assistant chief or chief engineer of small electrical plant 2000-5000 h. p. Eight years experience as chief electrician, electrical and steam engineer on power plant and industrial work. Operated turbines, corliss engines, automatically stoked boilers and electrical equipment, etc. Can operate precision machine tools. Fair technical education. Any reasonable salary accepted. E-2945.

ELECTRICAL ENGINEER. Technical education. Recently shift engineer in 90,000-kw. hydroelectric plant. Experienced on a-c. and d-c. installation and operation. Desires similar position. Age 28. Assoc. A. I. E. E. E-2946.

SUPERVISOR of Electrical Instrument Department in large plant desires to make a change. Has years of practical experience to back up first class executive, inventive, and designing ability. 14 years as supervisor of shops doing electrical and navigational instrument work, also fine machine shop practise. Associate A. I. E. E. Salary $3500. Services available at short notice. E-2947.

LOOKING FOR OPPORTUNITY, but would prefer work as assistant to an executive. Technical graduate, with three years practical work in engineering departments of power company and Westinghouse. Foreign field welcomed. E-2948.

TECHNICAL GRADUATE of Electrical Engineering course, '21, age 23, desires a position in electrical engineering work, preferably a consulting engineering concern. Have had 4 years practical experience, at shop work, drafting and testing in the electrical line. Available in about one week. E-2949.

YOUNG MAN evening student at City College New York, desires position with electrical concern. Two years experience with a motor manufacturing concern as laboratory assistant, repair man and tester of both individual parts and finished product. One year experience with company manufacturing electrical indicating instruments. Excellent references. E-2950.

SALES ENGINEER or REPRESENTATIVE for Rhode Island and vicinity, permanently located in Providence; desires connection with firm manufacturing commodity of merit requiring the services of a well trained engineer with good business experience. Would consider establishing agency. Age 34, married. E-2951.

TECHNICAL GRADUATE, age 29, desires connection with industrial engineering or power company. Experience in power plant and substation work, switchboards, wiring diagrams. Also in the manufacture of almost anything in the metal line. Single. Assoc. A. I. E. E. E-2952.

TECHNICAL GRADUATE B. S. 1919. Assoc. A. I. E. E., age 25, desires position as

assistant to electrical engineer in power plant or industrial concern. Eighteen months Westinghouse Test, also some electrical experience chiefly radio gained in the army. Energetic worker with plenty of initiative; good trouble shooter. Best of references; now employed; available upon two weeks notice. E-2953.

ENGINEER with technical education, 12 years experience in designing and manufacturing of starting, lighting and ignition equipment, also induction and fan motor experience. E-2954.

METER SUPERINTENDENT, thirteen years with large eastern utilities, desires to make connections with manufacturer as sales organizer in executive capacity in order to round out his experience, or will undertake to establish or reorganize a meter department or testing bureau for a growing company. E-2955.

GRADUATE ELECTRICAL ENGINEER, M. I. T., 1920, age 23, desires position with power company or assistant to chief engineer of large industrial concern. Experienced in steam and electrical testing as well as knowledge of central and substation equipment. Primarily want permanent position with chance of advancement. Location preferred, eastern states. E-2956.

M. I. T. GRADUATE 1918, electrical engineering desires to enter factory management organization in any capacity, where there exists real opportunity for progressive, technically trained man, who can eventually acquire position of responsibility. Previous experience in this line productive of results. Salary at start of secondary importance. Factory must be in Boston or vicinity. E-2957.

ELECTRICAL ENGINEER, age 21, graduate International Correspondence School, 1920, Assoc. A. I. E. E. Experienced in electrical contracting, factory wiring, motor and generator installation and maintenance. Eighteen months experience as first class electrician on construction and maintenance for oil refinery. Position with chance of advancement desired either on electrical construction, public utilities or with consulting electrical engineer. E-2958.

ELECTRICAL ENGINEER, technical graduate. Age 36. Married. Assoc. A. I. E. E. Four years experience in testing, design and maintenance work. Six years as sales engineer of electrical equipment. Desires position as sales engineer or sales manager. Salary $4200. Available on 30 days notice. E-2959.

ELECTRICAL ENGINEER, Master Mechanic. Technical graduate, age 33, married. Ten years experience construction and operation hydroelectric plants, Mexico, Central America, Colorado; mechanical operation metal mines, crushing, cyanide and oil flotation plants; seeks position with established companies or those contemplating construction. Speaks, reads and writes Spanish. Location no object. E-2960.

ENGINEER of broad teaching and industrial experience desires assistant or associate professorship in electrical engineering. Age 36. Two University degrees. E-2961.

MANAGER OR ASSISTANT. Can you profitably employ the services of a man with several years varied experience in the operation of utility properties? If so, we can correspond with mutual benefit. Technical, 36, married, and best of references. Write me today. E-2962.

YOUNG MAN, age 24, single, desires position with large power company as local operator in town of about 4000, with chance to work up to division managership. Four years experience in this work and now in charge of 11,000-volt station. Can also manage commercial end of business. Will begin on salary of $125.00 per month. Location desired Alabama or Tennessee. E-2963.

ELECTRICAL ENGINEER, age 26, technical education, 7 years experience contracting, testing and construction. Last 3 years with electrical traction company in executive capacity in connection with substation construction. Would prefer entering sales organization of electrical manufacturing concern. E-2964.

ELECTRICAL ENGINEER desires position as superintendent for industrial plant, power, or mining company. Experience covers operation, maintenance, and construction in hydroelectric plants, transmission lines, substations, mill and mine. Sound business training and thorough knowledge of Spanish. Age 28. Married. Available September 15th. E-2965.

ELECTRICAL ENGINEER, B. S. degree; age 21; unmarried; 6 months practical experience; good references. Desires connection leading to future responsibility with a power or manufacturing concern. Middle West location preferred but will go anywhere depending on offer. Initial salary immaterial; available on short notice. E-2966.

ELECTRICAL ENGINEER, University of Illinois graduate, 1912. Central station experience on substation design. Transmission line specifications and rights, and power rates and contracts. Industrial plant experience on power, heat and light installations and superintendence of operation. Desires position of stability and with chances for advancement. E-2967.

POSITIONS OPEN

EASTERN TECHNICAL SCHOOL has opening on its teaching staff for instructor in physics and elementary electricity. Young man, graduate of a four year electrical or mechanical engineering course with some practical or teaching experience preferred. The opportunity for advancement excellent. Reply stating age, education and training, experience and salary desired. Location Boston, Mass. X-604.

EASTERN TECHNICAL SCHOOL has opening for instructor in electrical machinery laboratory. Young men, graduates of a four year electrical or mechanical engineering course with some practical or teaching experience preferred. Opportunity for advancement excellent. Reply stating age, education and training, experience and salary desired. Location Boston, Mass. X-622.

INSTRUCTOR in electrical engineering to handle, principally, laboratory courses. Must have had experience as an assistant, or instructor, in a good laboratory. Additional testing experience with a manufacturing company is desirable. Location Northwest. X-629.

GRADUATE ELECTRICAL OR MECHANICAL ENGINEER, 1919, for sales work with oil company. Sales experience desirable. Location New York City. X-682.

TECHNICAL GRADUATE, preferably under 35 years of age, thoroughly conversant with principles, design and construction of high-tension high-frequency oscillatory apparatus such as condensers, oscillators, transformers, etc., which practically means a man with more or less wireless telegraphy experience. This apparatus is not used in wireless work of any kind, but circuits are more similar to wireless than any other types of circuits. There is an unlimited field for development as the process is so connected with the treatment of oils as to lead almost certainly, with its development, to revolutionary changes in many present refinery practises. Give details of past experience, present connections, age, present and anticipated salaries, etc. Location Missouri. X-710.

INSTRUCTOR for electrical engineering subjects. Good engineering training and experience. Location Kansas. X-715.

GRADUATE ELECTRICAL ENGINEERS, over 30 years of age. Experience in cable manufacture while desirable is not essential. Location N. J. X-741.

INSTRUCTOR, three or four years mathematical training, to teach freshman mathematics, college algebra, trigonometry and analytical geometry. Should have doctor's degree in mathematics from a recognized university. Salary depends upon qualifications and experience of man appointed. Send recent photograph and full statement of courses in mathematics studied and credentials regarding experience in teaching and ability in mathematics. Application by letter. Location Middle West. X-752.

INSTRUCTOR wanted for employes' classes in large electric utility corporation. Knowledge of psychological tests and rating scales desirable. Write fully experience and salary required. Location Ill. X-763.

SALES REPRESENTATIVE for New York and vicinity for boiler tube cleaner. Would be expected to make a stack to stack canvass, also report calls to this office to permit of our cooperating with him by means of follow-up letters. Liberal commission and splendid field for the sale of the tool in New York and vicinity. X-769.

ELECTRICAL ENGINEER with experience in investigation and research work, also construction and erection of radio systems. Application by letter only. Location New York City. X-800.

SALES ENGINEER for concern manufacturing boilers. Inquiries are coming in increasing numbers and these appear to indicate the general feeling amongst steam users that now is the time to prepare their power plants for the business boom that is expected to develop rapidly from now on. Sales engineer engaged through F. A. E. S. has earned more than $5000 a year. Location Pa. X-807.

ENGINEER to teach drawing, mathematics, etc. Prefer young man with machine shop experience. Write giving experience and salary desired. Location New York City. Application by letter. X-808.

UNIVERSITY OF WISCONSIN, Electrical Engineering Department, Madison, will appoint two instructors in electrical engineering. Salary $1500 to $1800 for nine months school year. Men with an unusually thorough grasp of fundamental electrical theory and a year or more experience in the engineering or teaching field are desired. X-779.

CORNELL UNIVERSITY has an opening for an instructor in electrical engineering. Must be a university graduate; one or two years practical experience desirable. Opportunity to pursue graduate work. Write school of Electrical Engineering, Ithaca, N. Y., giving qualifications and references. X-809.

RESEARCH ASSISTANT familiar with theory of transmission lines and a-c. machinery. Must be good in mathematics and a fair mechanical designer. Present appropriation for salary is $130 a month for 10 months. Will be allowed to attend a few classes in Cornell University. X-894.

MANAGER of sawmill property in Mexico, pine timber. Must have similar experience, understand operation by railroad and all phases of the business including sales. Mill of 300 M capacity per day. Must speak Spanish and be man of strong personality. Climatic conditions excellent. Location Mexico. X-823.

LOAD DISPATCHER for a large interurban and power company man having some operating experience preferred. Live wires wanted; excellent opportunity for experience and advancement; salary moderate to start. Application by letter. Give age, experience and education; also salary expected. Recent graduate or those with 2 or 3 years educational training desired. Location Central West. X-826.

ELECTRICAL ENGINEER with 2 to 5 years experience as designer on switchboards, substations and wiring diagramming. No vacancy at present. Send record of experience. Location Pa. X-832.

ELECTRICAL ENGINEER, technical graduate, 8 or 10 years experience on design of large generator units. Man with experience on inspecting generators in electrical plant given preference. Position temporary, 6 to 8 months. Location Pa. X-835.

INSTRUCTOR in sophomore drawing, mathematics (calculus), elementary mechanics (statics and dynamics), and mechanism. Opportunity of promotion both in rank and salary for right man. Courses are on cooperative plan, students working alternate four week periods in the in-

dustries. Work is continuous throughout the year, and the teaching staff is employed on a twleve months basis. Vacation of about one month from the middle of August to the middle of September. Write giving education, experience present salary, salary expected, information regarding your personality, and inexpensive photograph, letters of recommendation, references to whom we may write. Location Middle West. X-837.

SUPERVISING CONSTRUCTION ENGINEERS for installation of electrical equipment in power station. At least 10 years experience necessary. Location New York City. X-838.

Draftsman experienced in hydroelectric designs or in general electric drafting. Application by letter. Location Ala. X-840.

GRADUATE ELECTRICAL ENGINEER, preferably with some telegraph or telephone experience, or not having such experience, should have made an unusually good record in college and since graduation. Man without telephone or telegraph experience should not have graduated from an electrical engineering course more than six years ago. Location New York City. X-855.

INSTRUCTOR to teach Regents subjects. Engineering graduate preferred. Location New York. X-860.

PROFESSOR to take charge of department and teach mathematics and physics. Must have at least masters degree and should be a member of the Baptist church. University runs all year round. X-868.

GRADUATE ENGINEER who will be actual head, or dean, of College of Electrical Engineering. Must have industrial experience and organizing ability. Should have approximately $10,000 which would be invested with us so that he would have a personal interest both in the operation of the business and the profits accruing therefrom. Must be strong organizer and a man with a sympathetic viewpoint toward engineering education and young electrical engineers. Location Middle West. X-876.

INSTRUCTOR or ASSISTANT PROFESSOR. Should be graduate chemist or industrial chemist with 2 or 3 years practical experience in electrochemistry amd metallurgy. Location Pa. X-887.

ENGINEER to look after a steam turbine generator, a boiler plant and the electrical apparatus for a factory. The current 440-volt alternating and the plant is situated at Marquette, Michigan. Will be expected to make minor repairs on the motors and electrical equipment and look after the maintenance of the electrical equipment, turbine, and boiler plant. Location Michigan. X-895.

INSTRUCTOR Electrical Engineering to teach laboratory work. Location Washington (State). X-897.

ENGINEERS to take up sales work. Experience in selling unnecessary. Location New York. X-909.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED AUGUST 16, 1921

ANDERSON, BURTON E., Load Disptacher's Office, Pacific Gas & Electric Co., Oakland; res., 725 Chanslor Ave., Richmond, Cal.
ANDERSON, IDOF, Chief Electrician, Norton Company, New Bond St., Worcester, Mass.
ANGUS, ROY F., Engineering Dept., American Hard Rubber Co., 11 Mercer St., New York, N. Y.
ARCA, PEDRO P., Engineer, Compania de Electricidad del Rio de La Plata, Ltd., La Plata; res., Parral No. 583, Buenos Aires, Arg. Rep.
ATTWOOD, STEPHEN S., Instructor in Electrical Engineering, University of Michigan; res., 1520 Cambridge Road, Ann Arbor, Mich.
BARRETT, J. NICOLSON, Engineer, Otis Elevator Co., 1373 E. 6th St., Cleveland, Ohio.
BEYERSDORFER, FRED A., Tester, Brooklyn Edison Co., Inc.; res., 1831 Catalpa Ave., Brooklyn, N. Y.
BLANCHARD, HENRY, Chief Electrical & Mechanical Engineer, Maracaibo Electric Lighting Co., Maracaibo, Venezuela, S. A.
BOCKUS, GERALD L., Supt. of Power, City of Sherbrooke, 100 Belvedere St., Sherbrooke, Que.
BUCKLIN, A. H., City Electrician, Municipal Heat, Light & Power Distribution, City Hall, Burley, Idaho.
CAMPANARI, EVANGELISTA, Manager, Nicola Romeo & Co., Via 20 Settembre 33, Milan, Italy.
CARELESS, GEORGE M., Foreman Electro Plater, Electric Storage Battery Co.; res., 4426 N. 15th St., Philadelphia, Pa.
CARLSON, EDWIN L., Engineer, Pacific Tel. & Tel. Co., 507 Sheldon Bldg., San Francisco, Cal.
CHAPLEAU, DEAN D., Student Engineer, Testing Dept., General Electric Co.; res., 849 Union St., Schenectady, N. Y.
CHATLEY, CHARLES C., Asst. Electrical Engineer, B. F. Sturtevant Co., Boston; res., 177 Wachusett St., Forest Hills, Mass.
CHRISTEN, ARTHUR E., Superintendent, United Towns Electric Co., Ltd., Harbor Grace, Newfoundland.
COX, HAROLD J., Southern New England Telephone Co., New Haven; res., 251 Center St., West Haven, Conn.
CURTIS, EDWARD C., Engineer, Kansas Gas & Electric Co., Wichita, Kans.
DALY, CARL F., Chief Repairman, New England Tel. & Tel. Co., Arlington; res., 22 Jackson St., Medford Mass.
DEE, F. KYRL, Electrical Supt., Stock & Dee, 249 W. 14th St.; res., 204 W. 14th St., New York, N. Y.
DEREMER, JAMES S., Pilot Engineer, D. & R. G. R. R.; res., 330 E. 19th St., Denver Colo.
DUSTE, ARTHUR W., Asst. Plant Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.
EARLE, RALPH P., Central High School, Philadelphia; res., Primos, Delaware Co., Pa.
FAHNING, OTTO R., Electrical Designer, Stone & Webster, Inc., Boston Mass.; The American Sugar Refining Co., Consulting Board, 117 Wall St., New York, N. Y.
FOCHT, ALBERT W., Equipment Installer, Western Union Telegraph Co., Chamber of Commerce Building, Denver, Colo.
FULMER, WILLIAM A., Electrical Contractor, 2140 N. 12th St., Philadelphia, Pa.
GASCOIGNE, LOUIS, Supt., Fire Alarm Telegraph, City of Detroit; 647 E. Larned St., Detroit, Mich.
GILLIS, MELVIN D., Foreman, Air Compressor Testing Dept., General Electric Co.; res., 849 Napier Place, Lawrence Park, Erie, Pa.
GLASSE, ALFRED O., Asst. Engineer, with National Electrical & Engineering Corp., Dunedin, New Zealand.
GORDON, BERT E., Power Plant Supt., Utah Power & Light Co., Ogden, Utah
GOULD, HARRY A., Power Plant Engineer; 3999 Greenwood Ave., Oakland, Cal.
GRANER, GEORGE S., Foreman of Electric Construction, Phoenix Utility Co., Hazelton, Pa.
GUPTA, AMULLYA R., Foreman Electrician, Tata Iron & Steel Co. Ltd., P 6 Bungalow, P. O., Jamshedpur (via) Tatanagor, B. N. Ry., India.
HALL, ARTHUR B., Assembler, American Radio & Research Corp.; res., 15 William St., Medford, Mass.
HARMAN, EDWIN N., Automatic Switchman, New York Telephone Co., 121 Castle St.; res., 93 Lyceum St., Geneva, N. Y.
HARRIS, FRANK ST. C., Power Engineer, Clarke Bros. Ltd., Deep Brook, Nova Scotia.
HART, WILLIAM A., Chief Electrician, Phelps Dodge Corp., Stag Canon Branch, Dawson, New Mexico.
HATTINGH, JOHANNES T., Lecturer in Electrical Engineering, Technical College, Durban; res., Elandsfantein, Tarkastad, Union of South Africa.
HEATH, RALPH S., Sales Engineer Agent, General Electric Co., 720 Newhouse Bldg., Salt Lake City Utah.
HEMINGWAY, HARRY A., Cost Estimator & Analyst, General Electric Co., Lynn, Mass.
HENNEFER, ARTHUR McALLISTER, Electrical Contracting, 270 Downington Ave., Salt Lake City, Utah.
HEUSSER, EMIL, General Director, Fabrik Elektrischer Apparate, Sprecher & Schuh, A. G., Arrau, Switzerland.
*INYOUE, NOBORU, Student, Johns Hopkins University, Baltimore, Md.
JENSEN, MARION A., Iowas Service Co., Missouri Valley, Iowa.
JIMBO, SCIKICHI, Engineer of Electro-Technical Laboratory, Dept. of Communication, Tokyo, Japan.
JOHNSON, ARTHUR C. K., Sales Engineer, V. V. Fittings Co., 308 S. Canal St., Chicago, Ill.
JOHNSON, CHESLEY H., Professor in Science Dept., Northeast High School, Philadelphia; res., Summit Ave., Primos, Penn.
JONES, ALBERT F., Office Manager, C. H. Parker & Son Electric Co., 1520 Wazee St.; res., 2547 W. 29th Ave., Denver, Colo.
JONES, FREDERIC P., Electrical Engineer, Anglo-Newfoundland Development Co. Ltd., Grand Falls, N. F.; res., 136 Summer St., Biddeford, Maine.
JONES, SAMUEL W., Division Foreman, Bingham Div., Utah Power & Light Co., Bingham Canyon, Utah.
KAELBER, J. GEORGE, President & General Manager, Interstate Public Service Corp., 1028-1030 Granite Bldg., Rochester, N. Y.
KISSEL, WALTER P., Wire Chief, Mountain States Tel. &. Tel. Co.; res., 419 30th Street, Ogden, Utah.
KNOTT, CHARLES E., Valuation of Electric Power Plants & Substations, Pacific Gas & Electric Co., San Francisco; res., 1813 Bonita St., Berkeley, Cal.
KUHNS, JOHN H., Salesman, Hi-Voltage Equipment Company, 3305 Croton Ave., Cleveland, Ohio.
KULKA, EUGENE R.; res., 163 Lee Ave., Brooklyn, N. Y.
LANGFORD, WILBUR H., Acting Superintendent, Utah Power & Light Co., Preston, Idaho.
LATORRE, ROBERT J., Testing Dept., General Electric Co., 26 Nott Terrace, Schenectady, N. Y.
LINE, RICHARD, Chief Electrical Engineer, Simla Municipality, Simla, Punjab, India.
LIUNGE, PAUL, Engineering Dept., New York Edison Co., 130 E. 15th St., res., 61 Hamilton Place, New York, N. Y.

MACKLER, LOUIS, Asst. Leading Electrical Draftsman, New York Edison Co., 130 E. 15th St., New York, N. Y.
*MARION, FREDERICK R., Long Lines Engg. Dept., American Tel. & Tel. Co., Room 215, 195 Broadway, New York, N. Y.
MARLOWE, THOMAS, Draughtsman, Public Works Dept.; res., 600 Cashel St., Christchurch, N. Z.
MARTI, OTHMAR K., Electrical Tester, Allis-Chalmers Mfg. Co., Milwaukee; res., 512 68th Ave., West Allis, Wis.
MORTON, THOMAS Q., Supt., Power Plant; Assoc. Professor Mechanical Arts, Prairie View State Normal, Prairie View, Texas.
MOSS, ARTHUR E., Electrical Engineer, Kaponga Town Board, Kaponga, N. Z.
MUELLER, EDWIN, Supt., C. J. & F. E. Briner, 1607 Morgan St., St. Louis, Mo.
McCORMICK, ROLLIN D., Engineer, Western Electric Co., Hawthorne; res., 14 N. Ashland Ave., La Grange, Ill.
NORTH, JOHN R., Substation Operator, Southern California Edison Co., 423 S.-M. Blvd. Sawtelle, Cal.
PAGEL, CLARENCE J., Salesman, The Robbins & Myers Co., 408 Marshall Bldg., Cleveland, Ohio.
PELTON, WILLIS H., Dept. of Building & Maintenance, General Electric Co.; res., 1033 Smithson Ave., Lawrence Park, Erie, Pa.
PERRY CHARLES T., Electrical Engineer, City of New York, Dept. of Plants & Structures, St. George, S. I.; res.; 224 Wardwell Ave., Westerleigh, S. I., N. Y.
PRATT, CHESTER C., Supt., Utah Plant Mountain States Tel. & Tel. Co.; res., 933 Lincoln St., Salt Lake City, Utah.
RANDALL, ERNEST G., Electrical Repairman, Shepard Electric Crane & Hoist Co., Montour Falls, N. Y.
RICHARDS, OTHO C., Foreman, Motor Winding Dept., Wagner Electric Mfg. Co.; res., 6325 Spencer Place, St. Louis, Mo.
RIGGS, OLIVER T., Inspector, United Electric Light & Power Co., 514 W. 147th St., New York, N. Y.
ROSE, OTTO K., Instructor, Cass Technical High School, Detroit, Mich.
ROSENBERG, ABRAHAM, Electrical Engineer, The Tarf Co., 11-13 W. 113th St., New York, N. Y.
SCHAMBERGER, SANFORD O., Student Engineer, Testing Dept., General Electric Co.; res., 103 Seward Place, Schenectady, N. Y.
SCHIEMER, EDWARD W., Electrician, McCall Publishing Co., 236 W. 37th St., New York; res., 169 Park Ave., E. Rutherford, N. J.
SCHRYVER, FRANK J., Asst. Wire Chief, Western Union Telegraph Co., Dickinson, N. Dakota.
SCHANK, ROY B., Telegraph Engineer, American Tel. & Tel. Co., 195 Broadway, New York; res., 199 Stryker Ave., Woodside, N. Y.
STECK, M. M., Plant Engineer, Mountain States Tel. & Tel. Co., Salt Lake City, Utah.
STEPHENS, WILLIAM T., Engineer's Assistant, Operating Research Bureau, The Milwaukee Electric Railway & Light Co., Milwaukee; res., 226 Greenfield Ave., Wauwatosa, Wis.
TAGGART, WILLARD T., Electrical Inspector, Western Electric Co., 598 Finance Bldg., Philadelphia; res., Marietta, Pa.
TAYLOR, CLARENCE M., Asst. Supt., The Lincoln Electric Co., Cleveland; res., 1852 Charles Road, E. Cleveland, Ohio.
THOMPSON, EARL L., Chief Operator, The Depew & Lancaster Light Power & Conduit Co.; res., 45 School St., Lancaster, N. Y.
TOMLINSON, CARROLL M., Engineering Asst., Plant Dept., The Bell Telephone Co. of Pa., Pittsburgh; res., 909 James St., Wilkinsburg, Pa.
TUSH, JAMES W., Superintendent, Municipal Electric Light & Power; res., 125 N. 8th St., Martins Ferry, Ohio.
TWYMAN, NEAL, Electrician, Colorado United Mines Co., Wall Street, Colo.
VAN NORMAN, JAMES W., Asst. Work's Engineer, Canadian Explosives Ltd., James Island, B. C.
VEATCH, JAMES S., District Sales Manager, The Ohio Brass Co.; res., 536 Downing St., Denver, Colo.
VENKATARAM, V., Asst. Electrical Engineer, Walker, Sons & Co., Ltd.; c/o Postmaster, Nungavarm Post, via Trichinopoly, S. India.
WAGNER, GEORGE, Junior Electrical Engineer, Public Service Commission, 45 Lafayette St., New York; res., 34 Edson St., Corona, L. I., N. Y.
WHITALL, CHARLES W., White Oak Farm, Pawling, N. Y.
WICHMAN, RALPH D., 3155 Clay St., San Francisco, Cal.
WILCH, NOLE H., Repeater Attendant, American Tel. & Tel. Co.; Beaver Dam, Ohio.
WILLIAMS, JEROME H., Asst. Engineer, Interborough Rapid Transit Co., 600 W. 59th St.; res., 189 Claremont Ave., New York, N. Y.
YARLETT, WILBUR R., Instructor, Carnegie Institute of Technology, Pittsburgh; res., 435 Ella St., Wilkinsburg, Pa.
YATES, RAYMOND F., Associate Editor, Popular Science Monthly, 225 W. 39th St.; res., 81 Northern Ave., New York, N. Y.

*Former Enrolled students.
Total 99.

ASSOCIATES REELECTED AUGUST 16, 1921

HICKS, GEORGE E., Superintendent, The Syndicate Mining & Milling Co., Rico, Colo.
HIGSON, CHARLES R., Asst. to General Supt., Utah Power & Light Co.; res., 1224 E. 3rd South, Salt Lake City, Utah.
HOPKINS, ALFRED H., Chief Electrician, Consolidated Mining & Smelting Co., Trail, B. C.
JOHNSTONE, DOUGLAS M., Chief Operating Engineer, British Columbia Electric Railway Co., Ltd., Vancouver, B. C.
LANCASTER, JOHN G., Chief Electrical Engineer, Hay & Vickerman, Wellington, N. Z.
NIETHAMMER, FRIEDRICH, Professor of Electrical Engineering, German Technical University, Prag 1, Bohemia.
SHAVER, GEORGE W., Electrical Engineer, Utah-Idaho Central Railway; res., 638 23rd St., Ogden, Utah.

MEMBERS ELECTED AUGUST 16, 1921

AINSWORTH, CHESTER D., Chief Design Engineer, Condit Electrical Mfg. Co., S. Boston; res., 57 Phillips St., Wollaston, 70, Mass.
ALEXANDER, JAMES P., Sales Engineer Westinghouse Electric & Mfg. Co., New Haven, Conn.
BINDSHEDLER, THEODORE S., Electrical Engineer, Burroughs Adding Machine Co.; res., 1455 W. Philadelphia Ave., Detroit, Mich.
BREDBERG, STEN, Switchboard Engineer, General Electric Co.; res., 521 Lenox Road, Schenectady, N. Y.
CECCARINI, OLINDO O., Radio Designing Section, Western Electric Co., 463 West St.; res., 271 W. 12th St., New York, N. Y.
CHANG, TING CHIN, Professor of Electrical Engineering, Government Institute of Technology, 862 Siccawei Road, Shanghai, China.
DALZELL, HAROLD E., Chief Mechanical & Electrical Engineer, Southern Railways of Peru & Dependencies, Arequipa, Peru.
DYER, JOHN B., Electrical Engineer, Automotive Dept., Wagner Electric Mfg. Co., St. Louis; res., 135 Wesley Ave., Ferguson, Mo.
GUTHERZ, MARSHALL F., Manager, Electrical Dept., William H. Taylor & Co., 250-256 Hamilton St., Allentown, Pa.
JACKSON, EARLE D., Consulting Enginee 403 Endicott Bldg., St. Paul, Minn.
JOURDAIN, JAQUES, Director General, Campagnie Lorraine, d'Electricite, 64, Rue du Faubourg Stanislas, Nancy, France.
KORTHEUER, H. FRANCIS, Division Head, Engineering Dept., Western Electric Co., 463 West St., New York, N. Y.
LAUNDER, JOHN E., President, Independent Electric Machinery Co., N. E. Cor. 20th & Central Sts., Kansas City, Mo.
MARTINDALE, ROY, Asst. Operating Engineer, Bureau of Power & Light; res., 1026½ N. Alvarado St., Los Angeles, Cal.
REYNOLDS, LEWIS C., Electrical Engineer, Empire Gas & Electric Co., Geneva; res., 12 Tuxill Square, Auburn, N. Y.
STANSELL, GEORGE H., Electrical Engineer, Fisher-Body Ohio Co.; res., 13816 Coit Road, Cleveland, Ohio.
WALSH, N. STEVEN, Electrical Engineer, A. A. Giddings & Co., Ltd., 660 Dorchester St. West, Montreal, Que.
WALTER, ROSCOE G., Asst. General Superintendent, Wisconsin Power, Light & Heat Co.; res., 424 W. Wilson St., Madison, Wis.
WATERMAN, JOHN H., Mechanical & Electrical Engineer, Charles T. Main, 201 Devonshire St., Boston, Mass.
WEST, JAMES O., Electrical Engineer, The Willys Morrow Mfg. Co., Elmira; res., Wellsburg, N. Y.

TRANSFERRED TO GRADE OF FELLOW, AUGUST 16, 1921

BAILEY, BENJAMIN F., Professor of Electrical Engineering, University of Michigan, Ann Arbor, Mich.
FORTESCUE, CHARLES L., Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
HERZ, ALFRED, Engineer of Electrical Tests, Public Service Co. of Northern Illinois, Chicago, Ill.
LAWSON, CHARLES S., Section Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
WYMAN, FRANK T., President, Packard Electric Co., Ltd., St. Catharines, Ont.

TRANSFERRED TO GRADE OF MEMBER, AUGUST 16, 1921

BAER, FREDERICK L., Contract Sales Engineer, Automatic Electric Co., Chicago, Ill.
BEATTYS, WILLIAM H., Jr., Representative, Westinghouse Traction Brake Co., Chicago, Ill.
COLE, JAMES L., Asst. Superintendent, Westinghouse Elec. & Mfg. Co., Newark, N. J.
CROFT, TERRELL, Directing Engineer, Terrell Croft Engineering Co., St. Louis, Mo.
GUILDFORD, CHARLES T., General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
LAWSON, JOEL S., Sales Engineer, R. Thomas & Sons Co., New York, N. Y.
LEWIS, DONALD M., Secretary & Treasurer, General Manager & Chief Engineer, Livingston-Niagara Power Co., Avon, N. Y.
MARTIN, WILLIAM H., Dept. of Development and Research, American Telephone & Telegraph Co., New York, N. Y.
OSBORNE, CHARLES P., Supt. of Light & Power, Portland Railway, Light & Power Co., Portland, Ore.
ROBBINS, ARTHUR H., Supt. of Distribution, Electric Light & Power Co. of Abingdon & Rockland, North Abingdon, Mass.
RUSSELL, HERBERT A., Designing Engineer, Toronto Hydro-Electric System, Toronto, Ont.
TERVEN, LEWIS A., Electrical Engineer, Switchboard Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
THAU, WALTER E., Engineer, Marine Section, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WAGNER, EFFINGHAM B., Electrical Engineer, Lehigh Valley Coal Co., Wilkes-Barre, Pa.
WELLS, JAMES H., Chief Electrical Draftsman, Brooklyn Edison Co., Brooklyn, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held June 10 and August 8, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

BRUEGGEMAN, FRANK, Asst. Mechanical & Electrical Engineer, South Park Commissioners, Chicago, Ill.
CHRISTIANSEN, KAY C., Electrical Engineer & Supt. of Elec. Construction, Phoenix Utility Co., Hazleton, Pa.
COLVIN, C. W., Asst. Appraiser & Chief Engineer, Appraisal Dept., British Columbia Electric Ry. Co., Ltd., Vancouver, B. C.
CONDON, EDWARD J., President, Condon Engineering Co., Chicago, Ill.
CURTIS, ALFRED S., Telephone Engineer, Western Electric Co., New York, N. Y.
DAVIDSON, JOHN, Jr., Telephone Engineer, American Telephone & Telegraph Co., New York, N. Y.
DEMAREST, CHARLES S., Electrical Engineer, American Telephone & Telegraph Co., New York, N. Y.
FAIRLEY, G. E. A., Engineer, Buildings and Grounds, Carnegie Institute of Technology, Pittsburgh, Pa.
FIELD, CROSBY, Engineering Manager, National Aniline & Chemical Co., Inc., New York, N. Y.
HALL, GERALD R., Engineer, Apparatus Sales Dept., Canadian General Electric Co., Toronto, Ont.
HAMDI, ABDULLAH F., General Foreman, Test Dept., New York Edison Co., New York, N. Y.
KITTREDGE, CARLYLE, Chief Engineer, Michigan State Telephone Co., Detroit, Mich.
LANCASTER, JOHN G., Chief Electrical Engineer, Hay & Vickerman, Wellington, New Zealand.
MANVEL, FREDERIC I., Installation Engineer, General Electric Co., Pittsfield, Mass.
MORGAN, FRED, Electrical Engineer, Sessions Engineering Co., Chicago, Ill.
NEWLIN, EARL M., Engineer, Superpower Survey, U. S. Geological Survey, New York, N. Y.
PAGE, ROY, General Superintendent, Nebraska Power Co., Omaha, Neb.
PARSONS, OLIN D., Telephone Engineer, Western Electric Co., New York, N. Y.
PLUMB, HYLON T., Local Engineer, General Electric Co., Salt Lake City, Utah.
PROEBSTEL, D. W., Asst. Engineer, Portland Railway Light & Power Co., Portland, Ore.
RAKESTRAW, CLAUDE N., Supt. of Lines, Cleveland Electric Illuminating Co., Cleveland, O.
SUTHERLAND, WILLIAM F., Designing Engineer, Toronto Hydroelectric System, Toronto, Ont.
WARWICK, JOHN F., Engineer, Georgia Railway & Power Co., Atlanta, Ga.
WELLER, CLIFFORD T., Engineer, General Engineering Laboratory, General Electric Co., Schenectady, N. Y.
WORK, WILLIAM R., Prof. of Elec. Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1921.

Aubert, Francis, Mexico City, Mexico.
Bell, Trice M., Schenectady, N. Y.
Bond, T. Kirk, Tooele City, Utah.
Bush, Clarence R., Peoria, Ill.
Butler, V. Dell, Bull Run, Ore.
Castro, Jorge E., Mexico City, Mexico.
Cox, A. Walter, Youngstown, Ohio
Cunningham, John T., Brooklyn, N. Y.
Friend, Henry M., Brooklyn, N. Y.
Fukami, Gen-ichiro, New York, N. Y.
Gardner, Murray F., Lansing, Mich.
Gill, Clarence R., Chicago, Ill.
Gruner, Raymond W., Milwaukee, Wis.
Haldeman, Theodore T., Chatham, N. J.
Halperin, Herman, Cincinnati, Ohio
Harrop, Everett T., Worcester, Mass.
Hauser, Alberto, Mexico City, Mex.
Hickock, Harold C., E. Pittsburgh, Pa.
Higuchi, Nagao, New York, N. Y.
Humphries, Franklin R., (Member), Philadelphia, Pa.
Ihouye, Fukutane, New York, N. Y.
Johnson, Carl W. D., E. Pittsburgh, Pa.
Keefe, Walter L., Boston, Mass.
Lane, David M., New York, N. Y.
Leader, Alva A., Kingman, Ariz.
Leighton, Harold W., Boston, Mass.
Matel, Emil, Boston, Mass.
Matthews, Thomas, Grand Forks, N. Dakota
Maynard, Harold M., New York, N. Y.
Mercer, George G., Schenectady, N. Y.
Metlie, Paul J., West Allis, Wisconsin.
Morgan, Theodore B., Trenton, N. J.
Paolino, Serafino, Tiburon, Marin Co., Cal.
Nevins, Ennis, (Member), El Paso, Texas
Pineles, Seth M., E. Pittsburgh, Pa.
Roewe, George J., (Member), New York, N. Y.
Ross, Frank W., Allentown, Pa.
Scheinbeim, Hyman, Bronx, N. Y.
Scholz, Herbert J., Schenectady, N. Y.
Smith, George M., New York, N. Y.
Solis, Gregorio, Mexico, D. F., Mex.
Tao, Feng-shan, Philadelphia, Pa.
Williams, Isabelle C., New York, N. Y.
Wood, Franklin P., (Member), Denver, Colo.
Yoshida, Genzo, New York, N. Y.
Total 45

Foreign

Barat, Shivakrishna, Delhi, India
Buckley, John S., Santiago, Chile
Fernando, Savarimuthu, Trichinopoly, S. India
Fluck, Aaron C., Rancagua, Chile, S. A.
Govindraj, N., Simla, India
Hill, Ira B., Balboa, C. Z.
Ito, Harry I., Lihue, Kauai, Hawaii
Janitschke, Erick O., Pearl Harbor, T. H.
LeRoux, Hermanus S., Bethulie, O.F.S., S. Africa
MacLeod, Donald B., Rugby, Eng.
Nordin, John A., (Member), Finspong, Sweden
Nunn, Darrell, N. Woolwich, Eng.
Parker, Ray D., Havana, Cuba
Russell, Archibald J. G., Christchurch, N. Z.
Saevig, T., Aalesund, Norway
Stratton, Richard F., Madras, India
Total 16

STUDENTS ENROLLED AUGUST 16, 1921

13515 Ellis, Fred D., University of Michigan
13516 Chute, George M., Jr., University of Michigan
13517 Kaphan, Harold H., New York Electrical School
13518 Nordling, William G., Hew York Electrical School
13519 Vogt, Harry E., Mechanics Institute
13520 Hapgood, Kenneth E., Worcester Polytechnic Institute
13521 Thompson, Allan K., University of Southern California
13522 Pape, Erie, Pratt Institute
13523 Ryan, Ambrose A., Montana State College
13524 Michel, Charles J., Pratt Institute
13525 Bulkley, Olcott R., California Institute of Technology
13526 Snow, John G., Worcester Polytechnic Institute
13527 Finkle, George H., University of Wisconsin
13528 Hammatt, Edward R., New York Electrical School
13529 Rogers, Frank M., New York Electrical School
13530 Cody, Martin F., Jr., Cooper Union Night School
13531 Hill, Warren R., Worcester Polytechnic Institute
13532 Stonestreet, Nicholas V., University of Maryland
13533 Brown, Leland H., Stanford University
13534 Mendonca, Marcello P., Stanford Univ.
13535 Miller, Charles E., Stanford University
13536 West, William V., Stanford University
13537 Pearlmutter, Harry J., Tufts College
13538 Cline, Leon H., Clarkson College
13539 Koontz, Rufus G., University of North Carolina
13540 Culin, Harold G., Carnegie Institute of Technology
13541 Collier, Wilbur H., Johns Hopkins Univ.
13542 Lazarus, Louis, Brooklyn Polytechnic Inst.
13543 Lawrence, William D., Newark Technical School
13544 Hadlock, Perry F., Clarkson College of Technology
13545 Petty, Louis, New York Electrical School
13546 Harper, Alfred C., New York Eleotrical School
13547 Sidwell, Richard E., Drexel Institute
13548 Miller, Clifford K., Drexel Institute
Total 34

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*Louis Duncan, 1895-6-7.
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*Samuel Sheldon, 1906-7.
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Gano Dunn, 1911-12.
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Paul M. Lincoln, 1914-15.
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E. W. Rice, Jr., 1917-18.
Comfort A. Adams, 1918-19.
Calvert Townley, 1919-20.
A. W. Berresford, 1920-21.

*Deceased

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L. A. Ferguson, S. W. Stratton.
(Term expires July 31, 1923.)
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(Term expires July 31, 1924.)
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(Term expires July 31, 1925.)
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(Term expires July 31, 1926.)
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H. C. Don Carlos, G. J. Newton, W. K. Vanderpoel,
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Electric Auxiliaries on Merchant Ships

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WHEN we discuss the Merchant Marine, or any feature thereof, we must not lose sight of the fact that we are dealing with a commercial undertaking which is probably more highly competitive than any other. From its very nature this must be the case, for while each country can make laws to assist the merchant ship owners of that country, every effort to help them and penalize foreign shipping can and undoubtedly will be neutralized by laws of the countries with which they are trading. The only assistance, therefore, that can be given by legislation, outside of providing good port facilities, is to enact laws that will assure a good standard for ships and at the same time not impose penalties in operation to which owners of other countries are not subject.

So we see that the answer to the question, "Who is to carry the merchandise which has to be transported between the various ports of the world?" rests in a great measure with the owners and operators of ships; and because electricity makes possible many reductions in the cost of operation and at the same time enhances the earning power of a ship it is being used to an ever increasing extent for driving the machinery on ships.

On highly efficient new ships, especially motorships, practically all the auxiliaries are driven by electric motors. In the motorship the steam boiler becomes an auxiliary and it is apparent that much of the gain in economy secured by the oil engine would be sacrificed if steam auxiliary machinery were retained. In the steamship, the losses incident to the steam auxiliaries are not so apparent; nevertheless, they are there, a constant drain on the boilers and a continual handicap to any operator or engineer endeavoring to attain efficiency in operation.

It is recognized that a somewhat greater gain in fuel economy is generally secured on a motorship by the adoption of electricity for the reason that Diesel oil engines are employed to drive the generators. Oil engines might be used on steamships with a resultant reduction of fuel required for all purposes. However, there are certain good operating reasons why such an arrangement is not generally popular. It would be necessary to have an engineering force competent to operate and maintain the oil engine. As the pumps essential to the operation of the ship's main engine would be driven electrically, any interruption of the auxiliary oil engine might seriously interfere with the operation of the ship. Fuel oil would have to be suitable for the Diesel engine and in some cases this might necessitate carrying two kinds of fuel oil on ship with the incidental disadvantages. Duplicate equipments for heating, storing and filtering fuel oil would have to be installed. On a steamship, therefore, the most generally accepted practise is to install turbine-driven generator sets for auxiliary power.

At this particular time with the ships of the world tied up owing to lack of cargo, with other countries bending every effort to improve their merchant fleet, and with all men in this country who have the interests of our merchant marine at heart endeavoring to see into the future and maintain such advantage as we have secured due to the large increase in American registry, it would seem that the opportunity afforded by this joint meeting should prove of inestimable value, as engineering advancement can only be secured when a thorough knowledge and understanding of all conditions are recognized by both the manufacturers and users of machinery.

The problem is entirely an economic one. It is only because investigations show that the electrically equipped ship can be operated more economically and can earn more that the question is being discussed. It is the intention of the writer to endeavor to show why this is the case.

Not much information has been published relating to the details of costs of operation of ships. Studies indicate that on new ships electric auxiliaries will show a marked improvement in the economy of operation and will increase the net earning capacity. The future will show that many existing ships can be operated profitably by the substitution of electric for steam auxiliaries. The reasons for expecting such big savings are not at once apparent. Investigations indicate that the losses are partly due to innumerable small leaks and to radiation; in other words, it is the steam

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which is generated in the boilers but not put to useful work that in a great measure accounts for the high fuel consumption of many steam-driven ships. When it is recognized that steam is kept on hundreds of feet of piping from the boilers to the steering engine all the time, and in many ships it is always on all deck lines to avoid losses and leaks incident to expansion strains from alternately heating and cooling, and in the winter time there are often considerable extra losses incident to keeping steam on deck machinery to prevent freezing; it can be seen that it is not by any means entirely due to the inefficiency of steam auxiliaries themselves that we get a poor showing, but to the very nature of their application, which cannot be altered. The size of the evaporators fitted in many steamships is proof of the amount of steam that is made by the boilers and passed off into the atmosphere.

Auxiliary machinery on ships can be readily subdivided into two broad types:

(a) for deck use,

(b) for below-deck use.

The motors most suitable are enclosed, weather-proof for above deck, and ventilated for below deck.

It is not the intention to describe a number of different pieces of electric machinery for ships. A study of the technical papers shows an ever increasing amount of space being given to such descriptions. Thoroughly reliable, simple and substantial machinery of various designs has been developed.

Deck Machinery

Deck machinery, properly speaking (that is, all machinery which is exposed to the elements and which must be built with this in view) consists generally of cargo winches, anchor windlass, a certain number of capstans, mooring winches and sometimes special machinery on particular ships. It is true that the steering machinery is not generally exposed to the elements, but is, however, very often housed in an extremely damp compartment. Continuous operation is vital to the safety of the ship. It will be evident that only machinery designed and built for the service should be considered for the application. The service of deck machinery is of an intermittent nature except in some special ships, that is, certain tankers where the motors for driving the cargo pumps are mounted on deck.

Electric deck machinery has been developed along two fundamentally distinct lines: one, in which the motor is mechanically geared to the drums, and the other where some form of hydraulic speed reducing gear is fitted between motor and drum. The latter class seems to have found considerable favor abroad, where certain well-known manufacturers have developed winches using either the Williams-Jenney or Hele-Shaw hydraulic power transmission. Electric hydraulic power transmission is particularly well adapted for steering gear work and has been developed in this country. For general winch service the hydraulic pump and motor are excessively costly. A brief comparison of winches developed abroad and in this country would indicate as follows:

(a) That the speeds for given load are somewhat lower for the foreign-made winch. A drum speed of approximately 175 ft. per minute for 5000 lb. and 250 ft. per minute for 2000 lb. would seem to be good practise.

(b) Certain manufacturers abroad have developed very neat worm-driven winches. These if properly built should be very quiet and from the descriptions appear to be quite compact. The writer does not know of any winches of this type developed in this country. One particular merit of such a winch is that the gear is readily encased, lubricated and protected from the action of the weather.

(c) From several descriptions there appears to be a tendency abroad to operate the motors by contactors. While this arrangement has much merit, it takes up additional space and costs more to install. In one description it is stated that the contactor controller is below deck. This, of course, is possible only in certain cases. Where the winches are located over the cargo holds special space must be provided on deck for the control panels and this space, of course, must be properly enclosed.

(d) There would seem to be a tendency on the part of the foreign winch manufacturers to considerably complicate the motor and control by the addition of special safety devices. In the writer's opinion this will be found undesirable. One manufacturer in this country who has fitted about two hundred electric winches on ships during the past five or six years claims that special safety devices are not only unnecessary but are actually undesirable. For the reason that it must be kept in perfect operating condition at all times so as to function properly when called upon at infrequent intervals, it will be recognized that apparatus for such service is the most difficult of all to maintain. It must be remembered that winches are operated in various parts of the world by longshoremen at the ports and not by the personnel of the ship. Experience indicates that properly designed and substantial equipment is entirely suitable for the service and does not require complicated safety-guarding features.

(e) With the majority of foreign-built winches it would appear that a handwheel is used for operation. This necessitates a tiring and unnatural movement on the part of the winch man. The natural motion and therefore one which can be carried on for hours at a stretch without unduly tiring the operator is similar to working a pump handle, that is, to control by means of a lever raised to raise the load and depressed to lower the load.

For gear winches the series motor or compound-wound with very small amount of shunt winding is

the most desirable. Fig. 1 shows how the natural characteristic of the series motor makes it most suitable for winch service. It is found necessary to throttle the steam winch at light loads to reduce the speed. In practise, therefore, it approaches more nearly the speed of the electric winch. Many winches are fitted with winch heads. When handling cargo with these instead of the drum the rev. per min. will run up somewhat. However, the winch head being of smaller diameter than the drum, it is generally found that the rope speed on the winch head will be about right.

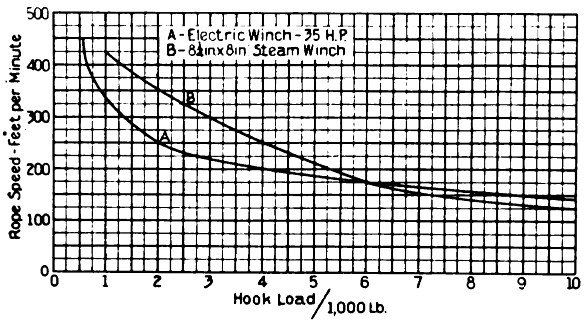

Fig. 1—Characteristic Curves of Electric and Steam Winches

For all service using hydraulic gear, constant-speed motors are used, either alternating-current or direct-current.

Of all the electric apparatus aboard a ship the winch is subject to the most abuse. Everything about it, therefore, should be designed, manufactured, and installed in the most substantial and workmanlike manner.

Specifications for electric deck machinery should cover the following:

1. Insulation should be as highly moisture-resisting as it is possible to get by the use and treatment of the best materials. This applies not only to windings but to all bushings, brush holder collars etc. which if hygroscopic are liable to result in grounds.

2. Motor frames should be thoroughly cleaned and painted on the inside to prevent so far as possible scale forming by corrosion.

3. Covers for inspection openings should preferably be hinged and arranged so as to clamp tightly. On all apparatus, motors, resistor boxes, controllers, etc., if it is impracticable to hinge the covers they should be attached by swinging bolts. Cap screws or cap bolts should not be used as they are liable to be dropped into the motor or left on deck and lost.

4. Bearings should be designed to prevent so far as possible ingress of water and egress of oil due to rolling of the ship.

5. All apparatus should be provided with some form of drain. It must be recognized that while machinery may be built in the factory so water-tight that it can be submerged, there is no assurance that this condition will exist after it has been once opened on deck. Further, any totally enclosed electrical apparatus is liable to breathe under varying temperatures which may result in an accumulation of moisture by condensation.

The cost of good electrically fitted machinery installed should be little, if any, more than that of high-grade steam machinery. Of course, until apparatus reaches a stage of standardized production the costs cannot be materially reduced. It must be remembered that while in steam machinery all kinds of economies may be practised at the cost of quality, in electrical apparatus built to withstand marine conditions and severe service a departure from the highest grade is most certain to be followed by failure and consequent cost to the operator. The making and insulating of electrical machinery cannot be materially hastened, as the successive dryings or bakings of the insulation must be given proper time—otherwise, it may be imperfect. The insulation in a marine motor must be moisture-resisting to the maximum practical extent—otherwise, it should not be deemed proper for the service.

Fig. 2 shows a deck winch developed in this country, several of which type will shortly be installed on ships. This winch is a radical departure from the generally recognized designs using either spur or worm gearing.

Electric steering gears have been developed for mechanical control of the rudder. For these the service is extremely intermittent, operating from two to ten times per minute, which means that the motor would be started, stopped and reversed thousands of times during one voyage. Such gears require the installation of a motor of sufficient torque to swing the rudder to the extreme angle, whereas during most of the time a very small amount of power is required. This means loss in efficiency as the motor is operating nearly all the time very much underloaded.

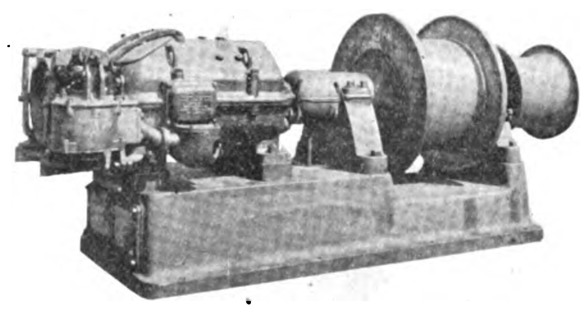

Fig. 2—New Type of Electric Cargo Winch Having the Reduction Gear Inside the Drum

For controlling the steering gear from the pilot house two electrical means are available, follow-up and non-follow-up. The first entails considerably more wiring, a multiple switch in the wheel house, a more complicated control in the steering engine compartment, and has the disadvantage of moving the rudder step by step a definite number of degrees. By the non-follow-up means the rudder can be moved by fractions of degrees in either direction; its use, however, calls

for the installation of a rudder indicator in the wheel house. A device has been worked out to show positively the position of the rudder at any instant, using simple means already developed.

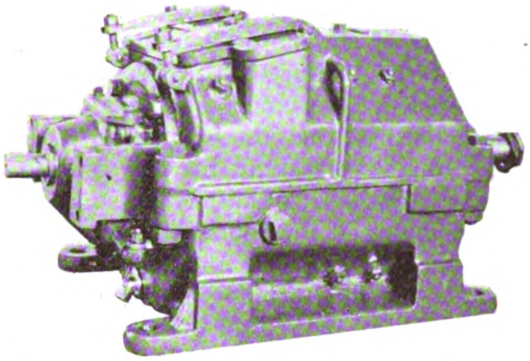

Fig. 3—Marine D-C. Motor—Enclosed, for Operating Deck Machinery

Special Deck Machinery. There are many special applications of electricity to machinery for shipboard not normally included as part of the regular equipment of a cargo ship wherein the use of electricity is particularly well suited. By the proper application of principles already worked out, it will be found that towing engines, mooring winches and other special pieces of machinery can be built to operate electrically in a very simple manner and with as great, or greater, reliability than steam machinery already developed.

The following is a table of deck machinery which with slight modification would be applicable to ships

Fig. 4—Marine Controller for Deck Machinery Motors

of any tonnage between 8000 and 10,000 tons dead weight. It should be borne in mind that the size of the cargo winches is based upon the best practise for general cargo and therefore does not vary greatly with the size of the ship. The number of winches, however, has to be modified to suit the number of hatches and derrick booms of the different ships.

	No. units	Assumed motor h. p.	Duty
Anchor Windlass	1	70	Very intermittent, severe Often submerged May be stalled in operation
Cargo Winches	12	35	Intermittent Fast cycle, severe duty Sometimes submerged Wide range in loads and speeds
Steering Gear	1	35	Seldom fully loaded Severe intermittent duty with mechanical gear Moderate continuous duty with hydraulic gear

TYPES DEVELOPED (ELECTRIC DECK MACHINERY)

	Drive	Motor	Speed Control
Anchor Windlass and Capstan	Spur-gear Worm-gear	Reversing	Electric
	Hydraulic	Constant-speed	Hydraulic
Cargo Winch		Reversing	Electric with electric brake (general use)
		"	Electric with mechanical brake
	Worm-gear	Constant-speed	Mechanical brake and clutch (free drum winch)
	Spur-gear	" "	Mechanical brake hoisting and lowering clutches
		" "	Reverse gear and brake
		" "	No speed control (winch head only)
	Hydraulic	Constant-speed	Hydraulic
Steering Gear	Spur-gear	Reversing	Electric Remote
	Worm-gear	"	" "
	Hydraulic	Constant-speed	Hydraulic "

Below-Deck Machinery

It should not be necessary to emphasize the importance of fitting equipment of proper design and of the highest grade material, particularly pumps vital to the operation of the ship and which must be relied upon to operate continuously day and night for weeks at a stretch.

The greater part of the electrical machinery below deck is naturally located in the engine room. The following table gives a list of below-deck auxiliaries suitable for a cargo ship of about 8000 to 10,000 dead weight tons and equipped with 2500 to 3000 shaft-h. p. steam turbine. A motorship requires somewhat fewer auxiliaries, and slightly less power is necessary for driving them. Tankers require a number of motor-driven pumps for discharging the cargo. These may be installed either in a special pump room or arranged with the motors on deck with vertical

shafts to the pumps below. It will be noted that in the list there are only five sizes of motors. That is with the intent of simplification and to reduce the number of spare parts to be carried. A study of particular cases may show that it is possible to arrange satisfactorily the engine room equipment so as to have still fewer sizes.

BELOW-DECK AUXILIARIES

	No. units	Assumed motor rating in h. p.	Duty
Propulsion			
1. Circulating pump	1	40	Continuous at sea
2. Boiler feed	2	25	One continuous at sea
3. Forced draft fan	1	20	Continuous at sea
4. Condensate	1	5	Continuous at sea
5. Lubricating oil	2	5	One continuous at sea
6. Oil cooler water	1	5	Continuous at sea
7. Fuel oil	2	5	One continuous at sea
8. Fuel oil trans.	1	5	Intermittent (assume 4 hr. per day
Service			
9. Fire and bilge	1	10	Intermittent (assume 6 hr. per day
10. General service	1	10	Intermittent (assume 6 hr. per day
11. Sanitary	1	5	Intermittent (assume 12 hr. per day
12. Fresh water	1	5	Intermittent (assume 2 hr. per day
13. Refrigerating	2	5	One continuous at sea
14. Evaporator	1	5	Intermittent (assume 3 hr. per day
15. Ballast	1	10	Intermittent (assume 4 hr. per day
16. Work shop	1	5	
17. Oil purifier	1	5	
18. Galley	1	5	

Motors for these auxiliaries should be designed for continuous running, because while certain pumps may be started and stopped frequently, the service cannot be considered intermittent.

In the engine room, and in fact even if placed in the lowest part of the ship, totally enclosed motors are not recommended. For continuous operation they would have to be excessively large. With the changes in the atmosphere that take place below the water line, enclosed motors would be more liable to sweat and accumulate moisture internally than if well ventilated. In general, enclosed self-ventilated motors are recommended for the reason that they are often located in congested places, where if open they would be liable to mechanical injury and in addition would have to be protected from dripping water. However, as electrical machinery when open is more readily inspected and kept clean, it is not essential that the motors be enclosed if located, *e. g.*, on a gallery and properly protected from dripping water. Such motors should be screened to prevent rats eating the insulation. On tankers, if the cargo pump motors are of the direct-current type and are located in a special pump room, they must be provided with some means of ventilation which will insure all explosive gases being driven off before the motors are started.

The motors in the engine room should be insulated with the same care and the castings as thoroughly cleaned and painted as the motors on deck. The insulation on all marine electrical apparatus should be made as highly moisture-resisting as possible.

As illustrating the adaptability of electrical apparatus, the writer recently saw a report from a chief engineer which stated that when the steam engines on his circulating pump and dry vacuum pump broke down he replaced them by two deck winch motors. The drive was so satisfactory that he intended to recommend that it be made permanent and incidentally the ship burned $1\frac{1}{2}$ tons of fuel oil per day less after the change.

Control. It would seem desirable that the means for starting and stopping each motor be located directly

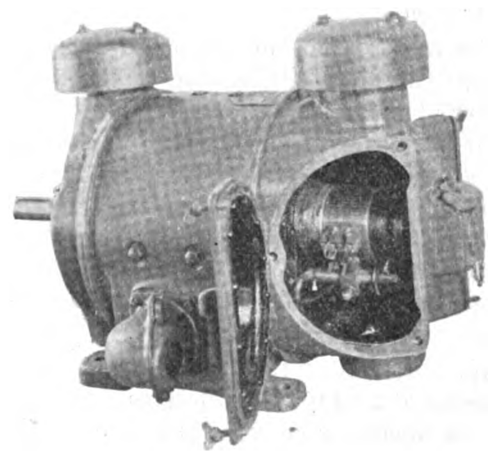

FIG. 5—MARINE D-C. MOTOR—ENCLOSED, VENTILATED, FOR OPERATING BELOW—DECK MACHINERY

adjacent to it. Such starters are relatively inexpensive. They should be very substantial and moisture-resisting. Thin sheet iron should not be used, especially on any part of the construction which cannot be readily painted, as after a short time it is liable to rust and may be the cause of serious trouble.

On steamships the motors on the circulating pump, lubricating oil pump, boiler feed pump, hot well pump, balancer set or lighting motor-generator set if any, and steering gear, should be fitted with starters so that when power is restored after an interruption these particular motors will immediately start up automatically. The other motors can be restarted by the engineer at his convenience.

Generating Units. A study of the installations on a number of cargo ships of various tonnages indicates that on a steamship 150 kw. would give ample power for the deck machinery when in port and for the entire engine room equipment when at sea. On a motorship about 75 kw. is necessary at sea. Therefore, on cargo ships of about 10,000 dead-weight tons, two 150-kw. steam turbines or on the motorships three

75-kw. generator sets would give ample power with one unit for a standby at all times. The auxiliary power in many cases will be much greater than 150 kw. *e. g.*, refrigerator ships and ships fitted in part for passenger service. The larger the amount of auxiliary power the greater the reason for highly efficient auxiliary turbines. Some studies have shown requirements for auxiliary power as great as 1500 kw.

Small steam turbines should be substantial and simple as they will be classed as part of the propelling machinery and therefore vital to the safety of a ship. In sizes of 150 kw. and even smaller, gear reduction would be recommended, as the best direct-current generator operation cannot be expected at the speed at which the turbine should run in order to get good economy. It is expected that these sets would be more substantial and conservative than sets of similar capacity for land service where they are at all times readily accessible.

For the reason that on shipboard there is always possibility of scale or salt passing to the turbine from the boilers it is preferable for the governor to control the speed by means of an oil Servo motor. All parts should be readily accessible. Even with the greatest care there is always liability that the lubrication may be momentarily interrupted, and as the bearings should be examined before the machinery is placed in service they should all be readily removable for inspection. An overspeed or emergency governor of the simplest and most reliable type should be fitted. Very specific and simple instructions should be issued to show the operating engineer the necessity of testing the governing mechanism periodically and assuring himself that it is in perfect operating condition.

THE MOST SUITABLE ELECTRIC POWER.

All references indicate that at the present time direct current is being generally adopted for auxiliary power on merchant ships. Some time ago there was considerable discussion as to the relative merits of alternating current and direct current. The following tabulation will show why direct current is being used to the greater extent:

CARGO SHIPS

DIRECT CURRENT

Arguments for	Arguments against
1. Simple wiring.	1. Commutators require some attention.
2. Any speed control easily obtained.	
3. Equally suitable for continuous and intermittent duty.	

ALTERNATING CURRENT

1. Lower cost of motors and generators.	1. Wiring more expensive.
2. Absence of commutators.	2. Unsuitable for variable speeds necessitating hydraulic or other gear for winches and windlasses.

TANKERS

DIRECT CURRENT

1. Simple wiring.	1. Commutators require some attention.
2. Equally suitable for continuous and intermittent duty.	2. Little necessity for variable-speed motors. Special cases could be fitted with hydraulic or direct-current power furnished from small motor-generator set.
3. Speed of cargo pump can be varied to suit pressures and most efficient rate.	3. Special precautions must be taken to ventilate motors in tank room.

ALTERNATING CURRENT

1. Lower cost of motors and generators.	1. Wiring more expensive.
2. Absence of commutators, particularly desirable in pump room.	2. Special motors necessary to change speed.
3. Cargo handled by constant speed pumps.	

It would seem that for cargo ships direct current can be used to the greatest advantage. On tankers this is not so apparent.

Except in the smaller ships, it is desirable to use not less than 230 volts. The lower voltage necessitates large or more expensive control; also the cost of wiring and switches is greater.

For lighting, the arguments seem to be in favor of 115 volts. This necessitates the installation of a small 115/230-volt motor-generator set. The use of incandescent lamps for 230 volts is not recommended. They are of necessity built with a very fine filament, and are, therefore, less substantial and further are not easily procured in seaports.

WIRING AND INSTALLATION

It is impossible to speak too forcibly on this subject. A great deal of critcism of electrical apparatus when thoroughly investigated has been found to be directly due to faulty, careless, slipshod methods of wiring and installation. Care and attention have been given to choosing apparatus, but the method of installation, the kind of wire, and many details of vital importance have been left to the wiremen's discretion with the inevitable result.

It is not the intention here to suggest that definite rules be laid down. Each engineer must work out his own particular problems. Certain underlying fundamentals, however, can generally be applied. The following are recommended:

That the wiring and distribution in the engine room be made as simple as possible, with relatively few circuits.

The switchboard should be largely a distribution panel designed with the idea of attaining maximum simplicity and occupying the least amount of engine-room space.

Circuits may be led from this distribution panel to different parts of the ship where they may be further subdivided, as *e. g.*, five circuits for deck machinery No. 1 to the steering engine, No. 2 to the after hatches No. 3 to the forward hatches, No. 4 to anchor windlasses,

and forward capstans, No. 5 to after capstans. This will permit opening all the winch circuits when at sea and also allow for thorough inspection and try out of the capstans, anchor windlass or steering engine when in port even if cargo is being handled.

In the engine room, a similar method may be applied, one circuit to the engine room auxiliaries, port side and another to the starboard side. By such simplification it will be possible to obtain low cost with maximum reliability.

Cables should not be run in conduits except perhaps for very short lengths where necessary for mechanical protection. Cables in the engine room should be run overhead. All cables should be thoroughly anchored so that the covering will not be chafed due to vibration.

Operation

To study the relative merits of ship's auxiliaries, it is necessary to consider the part which they play in the economic operation of the ship.

For certain special types of ships designed and built to operate for some particular service, such as tankers and lake ore carriers, it is not difficult to show definitely why a certain installation will give the best return on the investment.

In the cargo ship, however, the problem is not so clearly cut. While it is true that a certain number of ships may be designed with the intention of travelling particular trade routes and handling a special cargo it is often found that their schedule must be modified. Therefore, the general cargo ship must be built to handle all kinds of cargo and at best, therefore, the apparatus with which it is equipped is somewhat of a compromise.

It is not possible to make any exact general statement as to the proportions of the various items constituting the cost of operating merchant ships. They may, however be listed as follows:

1. Fuel and lubricating oil at sea and in port.
2. Port charges including wharfage, lighterage, pilot fees, canal dues, stevedoring, tug-boat charges, etc.
3. Salaries and subsistence.
4. Up-keep and repairs, deck department.
5. Up-keep and repairs, engine department.
6. Supplies, engine, deck and steward's departments.
7. Insurance.
8. Loss and damage.

If we assume a 7800-dead-weight ton ship fitted with 2500-h. p. steam turbine on a schedule for coastwise service between New York and Seattle, stopping at San Pedro to load and discharge cargo and making four round trips per year, the charges might be approximately as follows:

OPERATING DISBURSEMENTS

	Loaded both ways	Percentage	Loaded going one-half loaded returning
1. Fuel	$81,300	14.8	$81,300
2. Port charge	290,420	52.9	211,020
3. Salaries	60,490	11.0	60,490
4. Repairs, deck	10,000	1.8	10,000
5. Repairs, engine	20,000	3.7	20,000
6. Supplies	20,250	3.7	20,250
7. Insurance	62,400	11.4	62,400
8. Loss and damage	3,650	.7	3,650
Total	$548,510	100%	$469,110

Many of these would be affected by electrification of auxiliaries, and the net reduction would be very considerable.

1. *Fuel, etc.* In the usual marine geared turbine installation with steam auxiliaries, the pressures generally carried are as follows:

Boiler pressure	210 lb. gage
Turbine bowl	200 lb. "
Auxiliary steam line	100 lb. "
Auxiliary exhaust	10 lb. "
Superheat	75 deg. fahr

The auxiliary exhaust steam is used to heat the feed water and that which is in excess of feed-water heater requirements is by-passed to the main condenser.

Under full power, a fair operating average for this type of installation is as follows:

Steam consumption per hour:

Main turbine, 2500-h. p.	28875 lb.
Steam auxiliaries at sea	12500 "
Total steam consumption	41375 "

Steam per shaft horse power hour, all purposes:

$$\text{Steam per shaft h.p-hr., all purposes} \ldots \frac{41{,}375}{2500} = 16.5 \text{ lb.}$$

Boiler Evaporation:

With water-tube boilers, Howden draft system, feed water delivered to boilers at 220 deg., 210-lb. gage pressure and 75 deg. superheat, a conservative estimate of the actual evaporation per pound of fuel oil is taken at 13.5 lb.

Fuel Consumption:

$$\text{Fuel per hour} = \frac{41{,}375}{13.5} = 3065 \text{ lb.} \ldots = 9.6 \text{ bbl.}$$

Fuel per day ....73,560 lb. .... = 32.8 tons
Fuel in bbl. per day 230

Fuel per shaft horse power hour:

$$\text{Fuel per shaft horse power hour} = \frac{3065}{2500} = 1.23 \text{ lb.}$$

Fuel in barrels, per knot:

$$\text{Assuming a speed of 10.5 knots } \frac{9.6}{10.5} = 0.915 \text{ bbl. per knot}$$

The economy to be gained through the application of electrically driven auxiliary machinery, in fuel consumption alone, may readily be seen from the following estimates.

ELECTRIC AUXILIARIES

SUPERHEAT 75 DEG. FAHR.

Heating feed water:

The proposed method would be to extract sufficient steam from the turbine for feed water heater requirements.

Steam consumption, per hour:

Main turbine 2500-h. p.	30,600 lb.
Turbine generator	2,640 "
Air ejector	1,000 "
Total	34,240 lb.

Note: 3600 lb. per hour steam will be extracted from main turbine at about 10 lb. gage to heat feed water.

Steam per shaft horse power, all purposes:

$$\text{Steam per shaft h.p-hr., all purposes,} \quad \frac{34{,}240}{2500} = 13.7 \text{ lb.}$$

Boiler Evaporation:

Estimated for comparative purposes at 13.5 lb. per lb. of fuel. With the lesser quantity of steam to generate, however, the boiler efficiency would be improved in actual practise.

Fuel consumption:

$$\text{Fuel per hour } \frac{34{,}240}{13.5} = 2536 \text{ lb.} = 7.9 \text{ bbl.}$$

Fuel per day 60864 lb. = 27 tons
Fuel per day in bbl. = 189 bbl.

Fuel per shaft horse power hour:

$$\text{Fuel per shaft h.p-hr.} = \frac{2536}{2500} = 1.01 \text{ lb.}$$

Fuel in barrels per knot:

$$\text{Assuming a speed of 10.5 knots, } \frac{7.9}{10.5} = 0.75 \text{ bbl. per knot.}$$

The application of high superheat, well within the limits of present-day design, and electric auxiliaries present a very interesting and high economic value in ship propulsion.

ELECTRIC AUXILIARIES

SUPERHEAT 200 DEG. FAHR.

Steam consumption, per hour:

Main turbine, 2500 h. p.	27,000
Turbine generator	2,400
Air ejector	1,000
	30,400

Note: 3000 lb. per hour steam will be extracted from main turbine at about 10 lb. gage to heat feed water.

Steam per shaft horse power, hour all purposes:

$$\text{Steam per shaft h.p-hr., all purposes} \ \ldots\ldots \frac{30{,}400}{2500} = 12.15$$

Boiler evaporation:

Assumed at 13 lb. per pound of fuel.

Fuel consumption:

$$\text{Fuel per hour} = \frac{30{,}400}{13} = 2340 \text{ lb.} = 7.33 \text{ bbl.}$$

Fuel per day 56,200 lb. ..... = 25.1 tons
Fuel in bbl. per day .... = 176 bbl.

Fuel per shaft horse power hour:

$$\text{Fuel per shaft h.p-hr.} = \frac{2340}{2500} = 0.936 \text{ lb.}$$

Fuel in barrels per knot:

$$\text{Assuming a speed of 10.5 knots } \frac{7.33}{10.5} = 0.698 \text{ bbl. per knot.}$$

These estimates show the saving in fuel consumption by the use of electric auxiliaries, as follows:

Saving in Fuel Consumption (at sea):

Steam auxiliaries	230 bbl.	
Electric "	189 "	17.3 per cent
Electric " with 200 deg. fahr. superheat	176 "	23.5 per cent

Saving per year:

208 days at sea, oil at $1.50 per bbl.

Electric auxiliaries	8320 bbl.	at $1.50	$12,480
Electric " with 200 deg. fahr. superheat	11,250 "	" $1.50	16,900

In the estimate, an allowance was made of 40 bbl. per day in port. With electric auxiliaries, and economic engine room machinery, it should be possible to reduce this by one-half.

157 days × 20 lb. × $1.50 .... = $4,710

With a good system in the engine room, the lubricating oil required would be greatly reduced.

2. *Port Charges.* In giving thoughtful consideration to improving the earning power of a ship, it will be recognized as essential to decrease its idle time, as certain charges are continuous, whereas the ship is actually earning money only when traveling between ports. When it is realized that the average cargo ship makes only about 36,000 miles per year and that at an average speed of 10 knots, this means she is at sea only about 150 days out of a year, it is very evident that there is a big field for improvement.

Port charges estimated for the coastwise schedule mentioned above are as follows:

	N. Y.	Colon	Los Angeles	San Francisco	Seattle	Total
(a) Wharfage	$7800	....	$1560	$3120	$3120	$15,600
(b) Lighterage	....	....	....	....	....	....
(c) Pilots fees	202.56	....	200	250	....	652.56
(d) Stevedoring	7800	....	1560	3120	3120	15,600
(e) Tug-boat charges	100	....	....	200	....	300
(f) Canal dues	....	$4150	....	....	....	4,150
Total per trip						$36,302.56
Total per year (4 round trips)						$290,420.48

It will be evident that any means which will reduce the time a ship has to lie at the wharf loading or unloading cargo should lessen the two items *wharfage* and *stevedoring*. The writer has been informed of specific cases where ships have been delayed at docks due to freezing of steam deck machinery. He has also been informer of a specific case where two similar ships loading and unloading the same kind of cargo at the same dock and with the same stevedore foreman, the electrically equipped ship loaded in very much less time. Another specific case where a number of ships fitted with steam deck machinery had to await a derrick to assist in loading heavy cargo, where a ship fitted with electric machinery was able to handle its own cargo and saved a number of days delay.

Delays have been experienced with steam machinery due to low steam pressure. This may not be due to drop in boiler pressure but to loss in piping. With electric equipment, there is always ample power available for the winches.

By the use of the most suitable electric machinery, it should be possible to reduce the item of port charges 10 per cent. In the estimate given above this would mean approximately $30,000 per year saving.

3. *Salaries.* In all probability the salaries would not be directly affected. In the larger ships and in those where there is a very large amount of auxiliary power it might be found desirable to increase the salary slightly for one of the positions, in order to secure a man with electrical experience.

4. and 5. *Upkeep and Repairs.* Both of these items should be reduced. With properly designed electric machinery, the charges for repairs and maintenance would be less than with steam machinery. If compared with many existing ships a 20 per cent reduction would in all probability be a conservative estimate. If we only allow 10 per cent, however, this would mean a saving of approximately $3000 per year on the above estimate.

6. *Supplies.* This item would not be appreciably affected in the deck department, but for the engine department, there should be a material reduction.

A saving of 10 per cent might be expected, which would amount to $2000 per year.

7. *Insurance.* The assured reliability of proper electrical machinery in the engine room, along with the elimination of a large amount of piping carrying high-pressure steam, should have a direct bearing on the insurance rate. Indirectly, by reducing the loss of steam it should be possible to maintain the water in the boilers in almost perfect condition. This should still further add to the safety of a ship. It would seem to be justifiable to expect that the insurance premiums can be decreased about 5 per cent; this would mean a saving of approximately $3000 per year.

8. *Loss and Damage.* This item in all probability would not be affected.

The sum of the different gains mentioned above totals $55,190 per year. The amount of saving that can be shown by other estimates will naturally vary with conditions. In any estimates the possibility of making a substantial gain in the earning capacity in a ship is a real one. Having in mind certain ships, there is every reason to believe that the figures mentioned above might be increased.

One of the latest British combined cargo and passenger ships is equipped electrically and is fitted with over 100 motors driving auxiliary apparatus. Needless to say, the owners of new foreign ships are fitting them with electrically driven machinery only because they have satisfied themselves that it is profitable to do so. We engineers in this country should combine our efforts and avail ourselves of every opportunity to improve the efficiency of our merchant ships to the end that they may be able to compete successfully with the modern ships being placed in service by the other counties.

HYDROELECTRIC PROJECT FOR SOUTH CAROLINA

The Federal Power Commission has just issued for a period of two years, a preliminary permit to the Columbia Railway and Navigation Company of Columbia, South Carolina, which secures to it priority of application for a license for a navigable canal twenty-four miles long and not less than ten feet deep which will extend in a southeasterly direction from a point near Ferguson on the Santee River to the headwaters of the Cooper River. It is proposed to build a hydroelectric plant at the southerly terminus of the canal where a head of about 30 feet can be obtained. It is estimated that about 4000 h. p. of continuous power will be available while the secondary power available will perhaps amount to three times as much.

The proposed project contemplates the diversion of water from Santee River, which is navigable in its lower reaches, to Cooper River. The diversion of a large amount of water during low-water stages may have a detrimental effect on navigation on the Santee River. In order to protect the interests of navigation, the permit provides that surveys of the river shall be made and stream-discharge data collected, in order that the permissible diversion may be determined.

A study will be made of the effect that restrictions on the diversion of water from the Santee River will have on the economic operation of the power plant. Studies of the possibilities of storing water along the route of the proposed canal, of the extent to which Cooper River Valley will be flooded because of diversion of water into it, and of the silting of Charleston Harbor will also be made.

ELECTROLYSIS REPORT

During the past month the report of the American Committee on Electrolysis has been completed and it will soon be printed. This work will bring up to date the conclusions and recommendations that have been agreed upon as a result of a joint study of the electrolysis problem by the Bureau of Standards and the utility interests represented on the American Committee on Electrolysis.

During the month also the final experimental field trials of the earth current meter have been completed and the completion of these field trials has definitely established the utility of this instrument for practical electrolysis survey work. Plans are now being made to use several of these instruments in connection with the cooperative work of the Bureau and the Research Subcommittee of the American Committee on Electrolysis.

Gathering In Coal Mines

BY R. L. KINGSLAND

Consolidation Coal Company, Inc., Fairmont, W. Va.

IT was evidently the intention of your Committee that this paper should deal principally with a comparison of costs for different methods of gathering. One case, cited from records of the Consolidation Coal Company, will show that such comparisons are hardly practical. During 1916 coal was gathered for 5 cents per car. During 1920 coal was gathered with the same locomotive, from the same mines, and under mining conditions more favorable to the locomotives, for 20 cents per car. This increase is accounted for by large labor increase, poor and irregular railroad car supply, and decrease in efficiency of labor.

The above case shows the wide variation in costs due to changing conditions other than mining conditions. The different conditions encountered in different mines may give as wide variation in costs as the one above.

As costs for the past few years have not been comparable, and also as I do not have sufficient comparable figures for different methods of gathering under similar conditions for any one period, it will be necessary to confine this paper to a discussion of the different methods available for gathering coal and a short discussion of the limitations of each.

The simplest form of gathering is where the miners themselves push the cars into and out of the rooms. Obviously this method has great limitations, but it is still being employed in some places where the grades are in favor of the loads and where small cars are used.

Horses or mules probably still gather the greatest part of coal mined in the bituminous fields. Our experience has shown that a fair average for live stock gathering is two and one-half cars per hour or twenty cars for an eight-hour day.

We now come to mechanical gathering. This is a comparatively new field and I believe should be approached by the average mine operator with considerable caution. It is the writer's opinion that the cases where a decrease in gathering cost can be made, due to changing from live stock to mechanical gathering, are the exception, rather than the general rule. By this I do not mean to say that mechanical gathering does not have an important part to play in the coal mining of today. There are other reasons, aside from costs, which will justify replacing stock gathering with mechanical gathering: Such as, scarcity of labor, the attitude of labor against pushing any cars, and the fact that increased tonnage can be had from some mines due to less congestion in traffic with mechanical gathering.

Presented at the combined meeting of the Pittsburgh Sections of the A. I. E. E. and A. I. M. E., Pittsburgh, Pa., January 21, 1921.

The only power that we have used for gathering locomotives has been electric power, so I limit myself to electrically driven locomotives. Of these there are three principal types: Crab reel, cable reel, and storage battery locomotives. We have found that good results could not be obtained from the straight crab reel locomotive due to the excessive amount of labor required in pulling the cable into the rooms. Also this type of locomotive is not suited to pushing empty cars into the room. We have found, however, that in some mines, crab reels on part of our locomotives are very handy for odd jobs.

Cable reel locomotives, we consider as one of the most adaptable types for gathering. These locomotives are very flexible and have been successfully run with some very long cables. The principal trouble that we know of with them, is cable trouble. Inexperienced motormen will run over their cable frequently and cause considerable delay.

The third principal type is the straight storage battery locomotive. This locomotive has maximum flexibility as it can run anywhere, irrespective of feed lines and return lines, on its own power. There are, however, several limitations to the battery locomotive. It is limited in its day's work by the size of battery and the corresponding amount of energy which can be stored in same. Due to the weight of the battery, the locomotive can be abused by pulling too large trips, under which condition the battery energy will be expanded before the end of the day. The batteries require expert and systematic attention.

Our company has had considerable experience with combination trolley and storage battery locomotives. About 50 of these have been installed in one of our divisions. These are standard 250-volt, two-motor, six-ton locomotives, of the type usually used with cable reels. We have dispensed with cable reels and provided the locomotives with storage batteries in their place. The batteries receive boosting charges throughout the day, whenever the locomotives are running on trolley. The special field for this locomotive is where the mining work is scattered. The locomotive can gather a few cars in one place on the battery, and then run, on the trolley, to some other section for a few more cars. In comparison with the reel locomotives our mine people claim that it has extra flexibility. In comparison with the straight storage battery locomotives it has a much wider range of operation, due to its high speed on the trolley and the extra drawbar pull, which it is capable of exerting while on the trolley.

No mention has been made so far of room hoists. We have found it necessary to use these in some parts of our mines where the grades are too heavy for loco-

motives. As a general rule I would say that grades averaging 15 per cent are about as steep as can be successfully met with locomotives. We, of course, realize that locomotives have been, and are being, used on grades considerable in excess of this. The maximum grade on which I have seen a locomotive operate was 25 per cent.

The big question for the mining man is to know what type of locomotive to apply to the individual mine which he has under consideration. There are some mines where this question is very simple, but the majority of them will permit the installation of two or more types of locomotives and it is extremely difficult to determine which type will give the maximum results.

Let us assume as an average condition a mine that is at present gathering with live stock. The chances are that the mine will be developed so that in the majority of cases the grades will be in favor of the load. Part of the empty cars are delivered to the face with live stock and probably part of them are pushed from the room necks to the face by men. Also part of the loads are pulled from the face with live stock and the remainder are dropped from the face to the room necks by the men. In practically all cases the loads are not taken farther than the end of the room entry by the live stock. In most cases rooms are driven only one way from the room entry, and there are probably not more than six or eight rooms being worked on each entry. Under these conditions the live stock will average about 20 cars a day per head. In changing over to mechanical gathering, in order to make a favorable showing it would be necessary for each locomotive to replace four head of live stock. This would mean that two men with one locomotive would do the work of four men with four head of stock. It should be understood from the beginning that this result cannot be accomplished unless changes are made in the method of mining and condition of mine tracks. We have found in all cases where this change in the method of gathering has been made that it is necessary to improve materially track conditions so as to prevent derailment. Also the development work in the mines should be laid out so that each locomotive can get its full quota of loads from one room entry if possible, and in no case more than two room entries. Another important point is to avoid increasing the length of haul from the working faces to the side tracks in changing the gathering system. The tendency with most mine superintendents is to believe that the gathering locomotives should be able to haul farther than the stock, and they therefore expect them not only to gather as much as four head of stock but to haul these cars a greater distance to a side track than the live stock had previously done. All of the points mentioned above seem simple, but we have found by experience that they are quite important.

We will now turn to the special application of different types of locomotives. One undisputed field for the straight storage battery locomotive is in gaseous mines where no other type of locomotive is permissible. On the other hand, where heavy grades against the loads are encountered, the straight storage battery locomotive is not practical, as sufficient energy cannot be stored in it for the day's work. Between these two limitations there is left by far the biggest field where the different types of gathering locomotives meet on nearly equal grounds. Before leaving the battery locomotive I strongly advise against the installation of any such type of locomotives unless a sufficient number of them are installed so that they are accessible enough for a trained battery man to give each one regular and systematic inspection. Under general conditions I do not believe that it is advisable for an isolated mine to install one or two battery locomotives, unless it happens to have a man familiar with such equipment who will give them the necessary supervision. My strongest argument in support of this recommendation is the fact that we have been able to operate lead batteries in combination locomotives under the above recommended plan so that we have secured an average of about 50 per cent more than the guaranteed life on same. It should be noted that the service in combination locomotives is even more severe than that in straight storage battery locomotives, in so far as the batteries are concerned. This is due to the fact that in straight storage battery locomotives there are only one charge and one discharge per shift, while with combination locomotives the battery starts the day fully charged and is given boosting charges at frequent intervals throughout the day. This probably averages the equal of at least two full charges and two full discharges per shift, or twice the service demanded from straight battery locomotives.

In the case of a new mine that will be developed so that the work will be concentrated and each locomotive can get its full quota of coal from one or two room entries, and where the grades are not prohibitive, I would recommend the straight storage battery locomotive as being best suited for the work.

We still have left the majority of applications for gathering locomotives; that is, for operating mines that wish to install mechanical gathering. We have only eliminated from these mines, those that are gaseous, and those that have grades averaging 15 per cent or more. For the remaining mines consider that the straight storage battery locomotive has the smallest application. It should be applied to mines where the work is already concentrated, to those where the large part of the work will be concentrated within a short time, and to those where the maximum average grade is under 5 per cent.

There are now left the reel and the combination locomotives. I would recommend the reel locomotive for maximum average grades up to 15 per cent, and

the combination locomotive for maximum average grades up to 10 per cent. The latter limitation is made on account of the limited energy storage capacity of the storage battery. We have already given limitations which recommend against the use of storage batteries unless a sufficient number of them are installed close enough together for one battery man to keep close track of their care and operation. For the cases where there are not enough batteries to justify the services of one man for their care, I would recommend the cable reel locomotives. For the cases where there are a sufficient number of locomotives to justify the services of a battery man, I would recommend the combination locomotives. This recommendation is based on experience with both types of locomotives. The combination locomotives have been found more flexible, due to their lower speed and closer speed regulation when running from the battery. The battery should give about 125 volts while the reels have full trolley voltage of 250 or 500 volts. Also experience has shown that there are less delays due to batteries and accessories than due to cable reels and accessories. A locomotive with cable reels costs less than the same locomotive with storage batteries. I have found that the maintenance cost on one is about the same as that on the other. There is probably some small difference in power consumption of the two types. We have not made any accurate tests on this, because general results show that there is no appreciable difference. Our records show that the combination locomotive will gather from three to five cars more than the reel type per day, and we consider that this increase more than makes up for the extra investment necessary for the combination trolley and storage battery locomotive.

So far no mention has been made of mechanical gathering other than locomotive gathering and room hoists. Numerous systems of conveyers and scraper loaders have been suggested, but to date we have not found any that we could apply to our systems of mining so as to show a saving over locomotive gathering, nor have we seen our way clear to change our systems so as to suit any of the methods suggested.

When considering mechanical gathering for a mine, too much emphasis cannot be placed on the necessity of making mining conditions suitable for such gathering. For a new mine, where mechanical gathering will be used from the start, this should cause but little extra expense. For an old mine where live stock has been used extreme care must be taken in selecting the best method of mechanical gathering for the individual mine, all tracks must be put in good shape, the feed lines and returns must be ample for the service and ample side tracks must be provided as close as practical to the working faces. Also the more the mine workings are concentrated the better will be the results with mechanical gathering. Unless all of these things are watched closely the cost of mechanical gathering will show an increase over live stock gathering. With mechanical gathering the weight of locomotive can be suited to the weight of the cars. Under given conditions a locomotive should gather a certain number of cars per day. The larger the cars the larger the locomotive, but the number of cars gathered per day remains practically constant. Obviously the larger the car the cheaper the gathering cost per ton of coal mined.

TELEPHONE PROGRESS IN CHINA

A movement has been inaugurated to hunt up all the principal cities of China by long-distance telephone toll lines. This movement started with the business men of northern China who realize that little progress will be made in the unification of the country until modern methods of communication are adopted. The telephone is especially adapted to conditions in China, because the use of the telegraph is beset with many difficulties on account of the many characters in the Chinese alphabet which make it necessary to send all messages in code.

It is reported by Mr. Clark H. Minor, former Manager of the China Electric Co., of Pekin, who has just arrived in New York, that work has already begun on a long distance line between Shanghai and Peking that will connect with the toll system now in operation between the northern capital and Tietsin. The latter line, which has the distinction of being the only inter-city cable now existent in China, is only 100 miles long. The new line probably will be completed late this year. It will cost about $500,000 and will be constructed according to American standards.

New exchanges are also being erected in most of the larger cities to augment the 55,000 subscriber lines already in use in China. Girls are being trained for operators in Shanghai for the first time. It is also probable that girls will be used in the operation of the new system in the Yangtse valley. Hitherto due to the cheapness of male labor all work at the Chinese exchanges has been done by men. It is expected that it will require ten years to give China the telephone service its more active citizens desire.

ELECTRIFICATION OF JAPANESE RAILWAYS

The official system for the electrification of the railways of Japan has recently been revised and a new electric bureau established, states an issue of the Yokohama Chamber of Commerce Journal. According to the plan now being worked out by the Department of Railways, the first steps will be to electrify the entire Tokaido line, whose traffic has been increasing enormously each year, from Tokyo to Kobe, and a part of the Central line between Iidamachi station in Tokyo and Kofu, in the rear of Mount Fuji, where many tunnels make transportation slow. Electric trains will be used exclusively for passengers, freight trains being propelled by steam as at present.

Radiation From Transmission Lines

BY JOHN R. CARSON
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THE problem of radiation losses from transmission lines on which high-frequency currents are transmitted has become of considerable practical interest in view of the fact that in carrier wave transmission over wires, frequencies are now employed which are comparable with those utilized in radio communication. In discussing this problem I shall confine myself to a brief examination of two particular questions, the answers to which are, I believe, sufficient for engineering purposes, although they by no means constitute a complete solution of the problem.

The first question, which is suggested by some recent technical publications, may be explained as follows. In our usual engineering formulas for the propagation of alternating currents along wires, the attenuation of the current depends upon the dissipation in the wires and in the surrounding dielectric when leakage is present and vanishes in the ideal case of perfectly conducting wires in a perfectly non-conducting dielectric medium. The view appears to be rather prevalent among engineers that these formulas ignore the effect of radiation, and that in addition to attenuation by the dissipation, the current wave is also attenuated by radiation. The specific question arises, therefore, in transmission of alternating current along guiding wires, is the current wave attenuated by radiation, an effect which is entirely ignored in our usual engineering formulas.

Fortunately this question admits of a definite answer in the negative; the evidence for which I shall briefly state. Consider the case of two straight parallel wires of perfect conductivity in a perfectly non-conducting dielectric medium. The rigorous solution of the problem of wave propagation along such a system, starting with Maxwell's equations and determining the appropriate solution corresponding to the geometry of the system, is a comparatively simple problem and has been worked out long ago.[1] The result is that we find that the current is transmitted *with the velocity of light without attenuation* which agrees exactly with our engineering formulas. This is sufficient in itself to answer our first question as follows: *In transmission of alternating currents along straight guiding wires the current is not attenuated by radiation.*

This conclusion is amply confirmed by a number of investigations. For example, MacDonald in his book on Electric Waves, an Adam's Prize Essay of Cambridge University, states explicitly (Pg. 83): "It follows immediately that, for any number of parallel wires along which waves are traveling, the rate of radiation across any parallel cylindrical surface vanishes."

Again in a paper in the *Annalen der Physik,* Mie attacked the problem of wave propagation along two parallel wires in a fundamental and rigorous manner and arrived at conclusions which may be translated as follows (Pg. 248): "From an infinitely long line consisting of two parallel and equal wires of cylindrical cross-section, not the slightest trace of radiation passes out into the surrounding space even at the highest frequencies and at entirely arbitrary distances from the wires."

The foregoing conclusions are in direct disagreement with the theory recently advanced by Steinmetz (PROC. A. I. E. E., March 1919). In view of the fact that in this paper he has quite fully formulated a theory of radiation from wires which appears to be rather widely held among engineers, it may be well to summarize briefly his conclusions.

In a line which is transmitting high-frequency currents, Steinmetz states that there is, in addition to the energy consumption in the form of heat due to the ohmic resistance of the wires, an additional loss per unit length due to radiation of energy out of the system. This energy radiation, like energy dissipation by ohmic resistance, is accompanied by a counter electromotive force in the conductor or potential drop in the line. Consequently, the loss per unit length due to radiation can be accounted for by adding to the ohmic resistance per unit length of the line or conductor an additional "radiation resistance." According to this view the radiation resistance is a linear "constant" (or more precisely, parameter) of the line just as are the ohmic resistance, the inductance and the capacity. Steinmetz states that this linear radiation resistance increases as the square of the frequency when the line consists of parallel conductors (on which equal and opposite currents are flowing) provided the separation of the conductors is small compared with the wave length, which is always the case unless the frequency is enormous compared even with the highest frequency employed in radio transmission. He further states that when the line consists of a single conductor, the radiation resistance is at first directly proportional to the frequency and becomes proportional to the square of the frequency when the frequency is very high, and that the "radiation resistance" at high frequencies may be "thousands of times greater than the ohmic resistance" even when the increase of the latter with frequency is correctly taken into account.

The error which appears to underlie the conclusions of Steinmetz is strikingly similar to that commented

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1. See Abraham u. Föppl, Theorie der Elecktrizitat, Vol. I, pages 301-318.

on long ago by Heaviside.[2] In a discussion of transmission along wires, he points out that, in the vicinity of the wires, the energy flow is along the axes of the wires with a slight inclination *inward*. He then adds, "Professor Poynting, on the other hand (*Roy. Soc. Trans.* Feb. 12, 1885) holds a different view representing the transfer (of energy) as nearly perpendicular to a wire, *i. e.*, with a slight departure from the vertical. This difference of a quadrant can, I think, only arise from what seems to be a misconception on his part as to the nature of the electric field in the vicinity of a wire supporting electric current." Similarly all of Steinmetz' conclusions are based on the explicit assumption that the magnetic field is propagated outward from the surface of the wire at right angles to its axis with the velocity of light.

I shall now briefly take up the second question, namely the calculation of the order of magnitude of the radiation losses when high-frequency currents are transmitted over wire lines. In connection with this question the importance of the foregoing discussion is just this: Since the current is not attenuated by radiation, the energy losses due to radiation from the system as a whole must appear as terminal impedance corrections or reflection effects. To put this matter in another way, the generator in addition to the energy delivered to the line must supply the energy radiated, and our usual formulas ignore the latter effect. Again if at any point the spacing of the wires is changed or if the geographical direction of the line is changed, the amount of radiation is modified and this must appear as a reflection effect in the current wave which our formulas do not take into account. I have roughly sketched out the mathematical problems here involved. Their complexity is very great and a complete solution, so far as I am aware, has never been attempted. Fortunately, however, the representative calculation which I shall now give shows that the radiation losses to be expected from actual lines are so small as to introduce exceedingly small errors in our ordinary formulas.

The radiation from any known distribution of alternating currents can be calculated in a relatively simple and very elegant manner by making use of the Lorentz or retarded potentials by a method which appears to have been first applied to the calculation of radiation from a complicated system of currents by Poincare[3]. One ideal case of considerable theoretical and practical interest lends itself readily to calculation by this method, and the results of such calculation throw a great deal of light on the character of the phenomena and the orders of magnitude involved. This is the case of an ideal line consisting of two straight parallel wires of perfect conductivity of length x and separation y between wires. We suppose that alternating current of frequency $p/2\pi$ is transmitted along this line without attenuation and with the velocity of light c. We further suppose that the line is so terminated that there is no appreciable reflection of current. If σ denote x/τ where τ is the wave length the total radiation from the line is

$$S = 30\left(\frac{p\,y\,I}{c}\right)^2\left(1 - \frac{\sin 4\pi\sigma}{4\pi\sigma}\right) \text{ in practical}$$

units. To give a more definite idea of this magnitude let S_0 be the total radiation from a simple Hertzian oscillator of moment $y\,I$; that is a simple oscillator of length y and current I at frequency $p/2\pi$. Then

$$S_0 = 10\left(\frac{p\,y\,I}{c}\right)^2 \text{ in practical units}$$

and $$S = 3\,S_0\left(1 - \frac{\sin 4\pi\sigma}{4\pi\sigma}\right)$$

This formula is so simple as to require but little explanation. For very short lines the radiation is proportional to the fourth power of the frequency while for very long lines it is proportional to the square of the frequency and, as the length of the line is increased, approaches the limiting value

$$S \sim 30\left(\frac{p\,y\,I}{c}\right)^2 = 3\,S_0$$

As the length of the line is varied the radiation oscillates about this limiting value with decreasing amplitude. For example, when the line is 3/8 wave length long, the radiation exceeds that of the very long line by 20 per cent. If the wires are one foot apart, which is the usual spacing, and the frequency one million cycles per second, the radiation is only

$$0.0051\left(1 - \frac{\sin 4\pi\sigma}{4\pi\sigma}\right) \text{ watts / amperes}$$

That is to say the radiation effect is equivalent to an additional resistance in the generator circuit of only 0.0051 ohm. At 100,000 cycles per second, a frequency considerably higher than has as yet been commercially employed in wire transmission, this resistance is only 5×10^{-5} ohm.

To sum up, we may, I think, safely conclude that at any frequencies at all likely to be employed on actual lines the radiation effects are so small as to introduce no appreciable errors in our calculations. This conclusion is reinforced when we reflect that actual lines are transposed at frequent intervals and that the effect of such transpositions is to still further reduce the radiation losses.

2. Heaviside: Electrical Papers, Vol. II, pg. 94.
3. Conferences sur la Telegraphic, Sans Fil, 1909.

Theory of Magneto-Mechanical Systems as Applied to Telephone Receivers and Similar Structures

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A sufficiently general theory of magnetic vibratory apparatus is deduced to cover all practical problems in the operation of the various types of telephone receivers as transformers of electrical into acoustical or acoustical into electrical energy. A set of linear equations is derived relating currents in windings, mounted either on a stationary support (pole piece) or on the moving part (diaphragm or armature), and the motion of the moving part. The effect of eddy currents is included by treating each eddy circulation as a circuit. From the equations derived, it is possible by simple algebraic processes to calculate the effect of eddy currents and diaphragm or armature motion in terms of the constants or impedances of the system.

By making certain constants of the equations either infinite or zero the different receiver types are represented including (1) simple receiver without eddy currents, (2) receiver with eddy currents in the pole pieces, (3) receiver with eddy currents in the diaphragm, (4) receiver with eddy currents in both pole pieces and diaphragm, (5) receiver with the driving coil on the diaphragm, and (6) receiver with non-magnetic but conducting diaphragm.

Introductory

THE theory of the permanent magnet telephone receiver was first worked out from fundamental considerations of energy, using the Lagrangian method of obtaining the equations of motion, by Poincare, *Eclairage Electrique*, vol. 50, page 221, 1907, et seq. Interesting experimental studies of the ordinary telephone receiver have been published by Kennelly and his associates. The first of these, by Kennelly & Pierce, was "The Impedances of Telephone Receivers as Affected by the Motion of their Diaphragms" (*Proceedings of the American Academy of Arts and Sciences*, 1912, Vol. 48.) The general method used throughout these studies is the inference of the characteristics of the telephone from its impedance under various conditions.

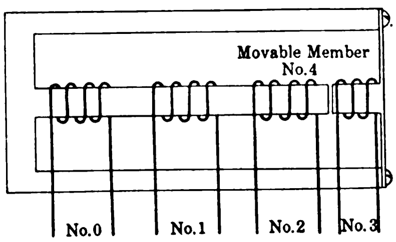


Fig. 1—Schematic Receiver

A number of other articles on the receiver has appeared in American and foreign periodicals during the last few years. They are concerned principally with methods of measurement of various constants.

This paper includes a somewhat more general theory of receiver structures and its application to the technique of measurement. The method used is applicable to any number of mutually dependent or independent electrical circuits magnetically coupled to any number of mechanical members, mutually dependent or independent. A paper by H. W. Nichols, "Theory of Variable Dynamical—Electrical Systems," *Phys. Rev.* August 1917, gives the general considerations of variable systems, of which the telephone receiver is a particular case.

General Theory

This section covers the theory of a sufficiently general electromagnetic vibratory mechanism to be applicable to any type of telephone receiver or transmitter operating on the principle of the reaction between relatively movable magnetic fields produced either by magnets or electric currents.

In Fig. 1, four coils are shown which are parts of four circuits. Coils Nos. 0, 1, 2, and 3 are situated so as to be inductively coupled each to each. Circuits Nos. 0, 1, and 2 are relatively fixed. No. 4 is a mechanical member free to move with one degree of freedom by a bending of its supports with respect to the support or core of members Nos. 0, 1, and 2. Coil No. 3 is constrained to move either with the mechanical member No. 4, or with a motion having a definite linear relation to the movement of No. 4. Fig. 1 illustrates schematically a single-pole telephone receiver. The movable member, No. 4, represents the diaphragm. Coil No. 0 carries a direct current to supply the steady magnetizing flux for the pole piece on which coils Nos. 0, 1, and 2 are mounted. Coil No. 1 represents the receiving coil which carries the telephone current. Coil No. 2 represents the eddy current circuit in the pole piece. Coil No. 3 mounted on the diaphragm represents the eddy current circuit in the diaphragm. A movement of the diaphragm, No. 4, alters the self and mutual inductances of all four electrical circuits.

Notation. Let L_0, L_1, L_2, and L_3 represent the self-inductances of circuits of which coils Nos. 0, 1, 2, and 3 are parts, L_{01}, L_{02}, L_{03}, L_{12}, L_{13}, and L_{23}, the mutual inductances between circuits as indicated by their subscripts, and L_4, the vibrating mass of the movable member.

Let R_0, R_1, R_2, and R_3 be the resistances of circuits of which the coils are parts and R_4—the mechanical dissipative resistance to motion of the movable member.

R_4 is assumed independent of the velocity of motion and gives, when multiplied by the square of the velocity of motion, the rate of dissipation of energy mechanically by the movable member. In order to conform with the electrical units adopted this resistance will be so chosen that the power dissipated is measured in watts.

Let C_0, C_1, C_2, and C_3 represent series capacitances or displacement of electricity in the condensers per unit of electromotive force in the corresponding circuits, and C_4 the mechanical "capacitance" or displacement per unit of force acting on the diaphragm. The reciprocal $1/C_4$ is the stiffness of the mechanical member.

Let i_0, i_1, i_2, and i_3 be currents flowing through the corresponding circuits, and $\dot{x}$ the velocity of motion of the movable member.

Let q_0, q_1, q_2, and q_3 be the quantities of electricity displaced as defined by $d\,q/d\,t = i$, and x the displacement of the movable member definable by $d\,x/d\,t = \dot{x}$.

Let E_0, E_1, E_2, and E_3 be the electromotive forces tending to produce displacement of electricity or current in the circuits and F the force tending to produce a displacement of the mechanical member.

f = frequency, $w = 2\,\pi\,f$ and $j = \sqrt{-1}$.

The first step in formulating a theory of this structure is to obtain the electromotive force equations or equations of motion; that is, a relation between the currents in the various circuit branches, velocity of motion of the mechanical member, electromotive and mechanical forces and electrical and "mechanical" impedances.

The reactions due to resistances and capacities in the various circuits are $i_0 R_0$, $i_1 R_1$, $i_2 R_2$, $i_3 R_3$, and q_0/C_0, q_1/C_1, q_2/C_2, q_3/C_3. Similarly the mechanical resistance and stiffness reactions are $\dot{x} R_4$ and x/C_4, respectively.

The reaction in an invariable circuit due to inductance is $L\,d\,i/d\,t$. In this case the inductances are variable, depending on the position, x, of the mechanical member. The motion is assumed to be small enough so that each inductance is a linear function of the mechanical displacement x and of the form $L\,(1 + k\,x_4)$ where L is the mean value of an inductance about which the variation takes place and k is a constant. On this assumption, $k\,x$ is small compared to unity. The inductive reactions are obtained from the kinetic energy, T, of the system by means of a differential formula due to Lagrange for mechanical systems and Maxwell for electrical systems. This formula is:

$$\frac{d}{d\,t}\left(\frac{d\,T}{d\,i}\right) - \frac{d\,T}{d\,q}$$

To get the inductive reaction in circuit No. o, i_0 and q_0 are used. The reactions in the other circuits are obtained by using the proper i and q. The mass reaction is found by using $\dot{x}$ and x.

The instantaneous kinetic energy of the whole system is

$$\begin{aligned} T = {} & 1/2\,L_0\,i_0^2 + 1/2\,L_1\,i_1^2 + 1/2\,L_2\,i_2^2 + 1/2\,L_3\,i_3^2 \\ & + 1/2\,L_4\,\dot{x}^2 + L_{01}\,i_0\,i_1 + L_{02}\,i_0\,i_2 + L_{03}\,i_0\,i_3 \\ & + L_{12}\,i_1\,i_2 + L_{13}\,i_1\,i_3 + L_{23}\,i_2\,i_3 \end{aligned} \qquad (1)$$

The force equation of any member, electrical or mechanical, is then given by an expression of the form

$$E = R\,i + \frac{q}{C} + \frac{d}{d\,t}\left(\frac{d\,T}{d\,i}\right) - \frac{d\,T}{d\,q}$$

Applying this formula to each member of the system, the following five equations of motion are obtained:

$$\left.\begin{aligned}
E_0 &= R_0\,i_0 + \frac{1}{C_0}\,q_0 + \frac{d}{d\,t}\,[L_0\,(1 + k_0\,x)\,i_0 \\
&\quad + L_{01}\,(1 + k_{01}\,x)\,i_1 + L_{02}\,(1 + k_{02}\,x)\,i_2 \\
&\quad + L_{03}\,(1 + k_{03}\,x)\,i_3] \\
E_1 &= R_1\,i_1 + \frac{1}{C_1}\,q_1 + \frac{d}{d\,t}\,[L_{01}\,(1 + k_{01}\,x)\,i_0 \\
&\quad + L_1\,(1 + k_1\,x)\,i_1 + L_{12}\,(1 + k_{12}\,x)\,i_2 \\
&\quad + L_{13}\,(1 + k_{13}\,x)\,i_3] \\
E_2 &= R_2\,i_2 + \frac{1}{C_2}\,q_2 + \frac{d}{d\,t}\,[L_{02}\,(1 + k_{02}\,x)\,i_0 \\
&\quad + L_{12}\,(1 + k_{12}\,x)\,i_1 + L_2\,(1 + k_2\,x)\,i_2 \\
&\quad + L_{23}\,(1 + k_{23}\,x)\,i_3] \\
E_3 &= R_3\,i_3 + \frac{1}{C_3}\,q_3 + \frac{d}{d\,t}\,[L_{03}\,(1 + k_{03}\,x)\,i_0 \\
&\quad + L_{13}\,(1 + k_{13}\,x)\,i_1 + L_{23}\,(1 + k_{23}\,x)\,i_2 \\
&\quad + L_3\,(1 + k_3\,x)\,i_3] \\
F &= R_4\,\dot{x} + \frac{1}{C_4}\,x + L_4\,\frac{d\,\dot{x}}{d\,t} - [1/2\,(L_0\,k_0\,i_0 \\
&\quad + L_{01}\,k_{01}\,i_1 + L_{02}\,k_{02}\,i_2 + L_{03}\,k_{03}\,i_3)\,i_0 \\
&\quad + 1/2\,(L_{01}\,k_{01}\,i_0 + L_1\,k_1\,i_1 + L_{12}\,k_{12}\,i_2 \\
&\quad + L_{13}\,k_{13}\,i_3)\,i_1 + 1/2\,(L_{02}\,k_{02}\,i_0 + L_{12}\,k_{12}\,i_1 \\
&\quad + L_2\,k_2\,i_2 + L_{23}\,k_{23}\,i_3)\,i_2 + 1/2\,(L_{03}\,k_{03}\,i_0 \\
&\quad + L_{13}\,k_{13}\,i_1 + L_{23}\,k_{23}\,i_2 + L_3\,k_3\,i_3)\,i_3]
\end{aligned}\right\} \quad (2)$$

Suppose now that the capacitance, C_0, is omitted, and a relatively large direct current flows in circuit No. 0 through a high enough impedance so that the reactions depending on $\dfrac{d\,i_0}{d\,t}$ can be considered negligible. The first equation then becomes $E_0 = i_0\,R_0$ and in this investigation will not be considered. The purpose of this circuit, it will be seen later, is only to supply a large permanent steady magnetic field. In a permanent magnet receiver this is a fictitious winding so disposed as to give the field, in magnitude and distribution, of the permanent magnet.

In the foregoing equations, i_0 occurs in products with other currents. Products of the small i_1, i_2, i_3, and x also occur. The terms containing these products involve reactions which are negligibly small

compared to those of the terms containing i_0. The term $1/2\, L_0\, k_0\, i_0^2$ is a constant entering the equation of mechanical force and determines the permanent deflection of the mechanical member from its equilibrium position. This term can be eliminated by measuring the displacement x from the equilibrium position when the large current i_0 is flowing.

If, in addition, we define

$$L_{01}\, k_{01}\, i_0 = b_{14},\; L_{02}\, k_{02}\, i_0 = b_{24},\; L_{03}\, k_{03}\, i_0 = b_{34},$$

and neglect the second order terms as explained above, the above five equations are reduced to four as follows:

$$\left.\begin{aligned} &L_1\, d\, i_1/d\, t + R_1\, i_1 + (1/C_1)\, q_1 + L_{12}\, d\, i_2/d t \\ &\qquad + L_{13}\, d\, i_3/d\, t\; b_{14}\, \dot{x} = E_1 \\ &L_2\, d\, i_2/d\, t + R_2\, i_2 + (1/C_2)\, q_2 + L_{12}\, d\, i_1/d\, t \\ &\qquad + L_{23}\, d\, i_3/dt + b_{24}\, \dot{x} = E_2 \\ &L_3\, d\, i_3/d\, t + R_3\, i_3 + (1/C_3)\, q_3 + L_{13}\, d\, i_1/d\, t \\ &\qquad + L_{23}\, d\, i_2/d\, t + b_{34}\, \dot{x} = E_3 \\ &L_4\, d\, \dot{x}/d\, t + R_4\, \dot{x} + (1/C_4)\, x - b_{14}\, i_1 - b_{24}\, i_2 \\ &\qquad - b_{34} i_3 = F \end{aligned}\right\} \quad (3)$$

It will be seen from dimensions that the quantities b_{14}, b_{24} and b_{34} are either back electromotive forces per unit velocity of No. 4 or forces on No. 4 per unit of current.

The free vibrations of this system are obtained by placing $E_1 = E_2 = E_3 = F = 0$ and solving for the free periods and the damping in the usual way. The expressions thus obtained, except for the simplest cases, are very complex and will not be of interest in connection with this treatment.

For forced vibrations, each value of E and F may be considered to be of single frequency. If a number of frequencies act simultaneously, they may be considered separately since in any system represented by a set of linear equations such as these the law of superposition holds.

We will therefore consider each value of E to be sinusoidal and to contain e^{jwt} as a factor. The forms of the i's, q's, $\dot{x}$, and x will then be complex and contain the periodic symbol e^{jwt} as a factor. Under these conditions $d/d\, t$ can be replaced by $j\, w$ and $\int d\, t$ can be replaced by $1/j\, w$. When this is done the above equations become

$$\left.\begin{aligned} &(j\, w\, L_1 + R_1 + 1/j\, w\, C_1)\; i_1 + j\, w\, L_{12}\, i_2 \\ &\qquad + j\, w\, L_{13}\, i_3 + b_{14}\, \dot{x} = E_1 \\ &(j\, w\, L_2 + R_2 + 1/j\, w\, C_2)\; i_2 + j\, w\, L_{12}\, i_1 \\ &\qquad + j\, w\, L_{23}\, i_3 + b_{24}\, \dot{x} = E_2 \\ &(j\, w\, L_3 + R_3 + 1/j\, w\, C_3)\, i_3 + j\, w\, L_{13}\, i_1 \\ &\qquad + j\, w\, L_{23}\, i_2 + b_{34}\, \dot{x} = E_3 \\ &(j\, w\, L_4 + R_4 + 1/j\, w\, C_4)\, \dot{x} - b_{14}\, i_1 - b_{24}\, i_2 \\ &\qquad - b_{34}\, i_3 = F \end{aligned}\right\} \quad (4)$$

The coefficients of currents i_1, i_2, i_3, and velocity $\dot{x}$ are seen to be impedances. Using the standard notation, Z, for impedance, these equations can be written

$$\left.\begin{aligned} Z_{11}\, i_1 + Z_{12}\, i_2 + Z_{13}\, i_3 + Z_{14}\, \dot{x} &= E_1 \\ Z_{12}\, i_1 + Z_{22}\, i_2 + Z_{23}\, i_3 + Z_{24}\, \dot{x} &= E_2 \\ Z_{13}\, i_1 + Z_{23}\, i_2 + Z_{33}\, i_3 + Z_{34}\, \dot{x} &= E_3 \\ -Z_{14}\, i_1 - Z_{24}\, i_2 - Z_{34}\, i_3 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (5)$$

The significance of these equations will be better understood by pointing out their similarity to those of a familiar electrical analog.

Fig. 2 is the diagram of a four-winding transformer. Coils Nos. 1, 2, and 3 are parts of three circuits which correspond to circuits 1, 2, and 3 of the mechanism of Fig. 1. It will be of interest to compare the effect of circuit No. 4, which is like Nos. 1, 2, and 3, with that of the mechanical member, No. 4.

The same method of deriving the "equations of motion" or impedance equations can be employed for this simple transformer, but the theory of electrical networks is in such common use that this is unnecessary. The equations can be written directly.

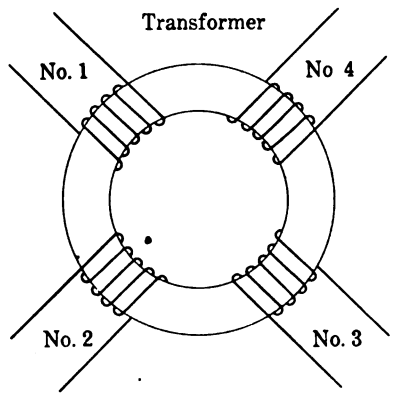


Fig. 2—Four-Winding Transformer

$$\left.\begin{aligned} &(j\, w\, L_1 + R_1 + 1/j\, w\, C_1)\; i_1 + j\, w\, L_{12}\, i_2 \\ &\qquad + j\, w\, L_{13}\, i_3 + j\, w\, L_{14}\, i_4 = E_1 \\ &(j\, w\, L_2 + R_2 + 1/j\, w\, C_2)\; i_2 + j\, w\, L_{12}\, i_1 \\ &\qquad + j\, w\, L_{23}\, i_3 + j\, w\, L_{24}\, i_4 = E_2 \\ &(j\, w\, L_3 + R_3 + 1/j\, w\, C_3)\; i_3 + j\, w\, L_{23}\, i_2 \\ &\qquad + j\, w\, L_{13}\, i_1 + j\, w\, L_{34}\, i_4 = E_3 \\ &(j\, w\, L_4 + R_4 + 1/j\, w\, C_4)\; i_4 + j\, w\, L_{14}\, i_1 \\ &\qquad + j\, w\, L_{24}\, i_2 + j\, w\, L_{34}\, i_3 = E_4 \end{aligned}\right\} \quad (6)$$

The coefficients of the currents are impedances and can be written:

$$\left.\begin{aligned} Z_{11}\, i_1 + Z_{12}\, i_2 + Z_{13}\, i_3 + Z_{14}\, i_4 &= E_1 \\ Z_{12}\, i_1 + Z_{22}\, i_2 + Z_{23}\, i_3 + Z_{24}\, i_4 &= E_2 \\ Z_{13}\, i_1 + Z_{23}\, i_2 + Z_{33}\, i_3 + Z_{34}\, i_4 &= E_3 \\ Z_{14}\, i_1 + Z_{24}\, i_2 + Z_{34}\, i_3 + Z_{44}\, i_4 &= E_4 \end{aligned}\right\} \quad (7)$$

There are two notable differences between this set of equations and that of the "magneto-mechanical" device. The mutual impedances b_{14}, b_{24}, b_{34}, between the coils and the mechanical member are constants, independent of frequency and involve no phase difference between the current and induced force, while in the transformer the corresponding mutual impedances, $j\, w\, L_{14}$, $j\, w\, L_{24}$, and $j\, w\, L_{34}$ are proportional

to frequency and involve a phase difference of 90 deg. between the inducing current and induced electromotive force. The mutual impedances, b_{14}, b_{24}, b_{34}, are of the character of resistances, in that they are in phase with the currents but are unlike resistances in that they are non-dissipative, which is shown by the fact that their signs in the electrical equations are opposite to those in the mechanical equation (See equations **4** and **5**). The analogy between the transformer and the receiver is not complete because of the difference indicated by these differences in sign.

The difference may be illustrated in another way, by an application of the "principle of reciprocity" which for a pure electrical network may be stated;

In any invariable electrical network, if any electromotive force, E, is applied in any branch and the current I measured in any other branch their ratio E/I is equal in magnitude and phase to the ratio obtained if the positions of E and the measurement of I be reversed.

This principle can be proved directly from the symmetrical form in magnitude and phase of the equations of a network of which the transformer (Eq. **7**) is an example.

The same reciprocal relation holds between displacement or velocity and mechanical force in an invariable "mechanical network," composed of any combination of elastic and inertia members, with or without damping.

In a "magneto-mechanical network" such as the one under discussion in this paper a similar principle can be formulated. For the sake of brevity a variable dynamical-electrical system in which the only variations are small changes of inductance will be alluded to as a "magneto-mechanical network."

In a "magneto-mechanical network," the ratio of an electromotive force placed in any electrical branch to the resulting displacement (or velocity) of a mechanical member (or branch) is equal in magnitude but opposite in phase (180 deg.) to the ratio of a mechanical force acting on the same mechanical member to the resulting current in the same electrical branch.

This can be proved directly from the symmetry of magnitude and asymmetry in signs in the characteristic equations No. 5, of a "magneto-mechanical network" of which the subject of this paper is an example.

In regard to the transfer of power from one circuit to another, from one mechanical vibratory element to another or from an electrical to a mechanical element or vice versa these systems are alike. For a maximum transfer of power the impedance of an element which is to be fitted to another must be the conjugate of the element to which it is fitted. This follows directly from equations 5 or 7, which are typical though not general.

A number of general expressions will next be derived for the calculation of the various currents and velocity and impedance characteristics. A set of linear equations of this kind is manipulated most easily by the short hand method of determinants.

For convenience, define

$$Z_{21} = Z_{12},\ Z_{31} = Z_{13},\ Z_{32} = Z_{23},\ Z_{41} = -Z_{14},$$
$$Z_{42} = -Z_{24},\ Z_{43} = -Z_{34}$$

Rewrite equations **5**.

$$\left.\begin{aligned} Z_{11}\,i_1 + Z_{12}\,i_2 + Z_{13}\,i_3 + Z_{14}\,\dot{x} &= E_1 \\ Z_{21}\,i_1 + Z_{22}\,i_2 + Z_{23}\,i_3 + Z_{24}\,\dot{x} &= E_2 \\ Z_{31}\,i_1 + Z_{32}\,i_2 + Z_{33}\,i_3 + Z_{34}\,\dot{x} &= E_3 \\ Z_{41}\,i_1 + Z_{42}\,i_2 + Z_{43}\,i_3 + Z_{44}\,\dot{x} &= E_4 \end{aligned}\right\} \quad (8)$$

Denote the discriminant of this system, or determinant of the coefficients of current by D, and its minors by D with proper subscripts. To illustrate: D_{13} is the first minor of D obtained by suppressing row 1, and column 3 of the coefficients; D_{13}^{24} is a second minor determinant with row 2 and column 4 eliminated in addition.

Inspection will show that a relation similar to that between mutual impedances holds for the first minors of this discriminant,

$$D_{21} = D_{12},\ D_{31} = D_{13},\ D_{32} = D_{23},$$
$$D_{41} = -D_{14},\ D_{42} = -D_{24},\ D_{43} = -D_{34},$$

In the purely electrical system, as in equations **7**, corresponding minors are identical in sign as well as in magnitude.

The solutions for currents i_1, i_2, i_3 and velocity of motion of No. 4, $\dot{x}$, are directly written.

$$\left.\begin{aligned} i_1 &= (E_1 D_{11} - E_2 D_{21} + E_3 D_{31} - F D_{41})/D \\ i_2 &= (-E_1 D_{12} + E_2 D_{22} - E_3 D_{32} + F D_{42})/D \\ i_3 &= (E_1 D_{13} - E_2 D_{23} + E_3 D_{33} - F D_{43})/D \\ \dot{x} &= (-E_1 D_{14} + E_2 D_{24} - E_3 D_{34} + F D_{44})/D \end{aligned}\right\} \quad (9)$$

As a rule, of course, only one electromotive force, E, or mechanical force, F, acts at a time so these expressions are greatly simplified by placing the others equal to zero. The expressions for various current ratios, ratios of current or velocity to applied electromotive force or mechanical force are easily written from equations 9. In particular, the ratio of any electromotive force, E, to the resulting current i in the same element is the "driving point" impedance of the system. The ratio $F/\dot{x}$ is a driving point impedance and is given in mechanical units—dynes per centimeter per second. The "driving point" impedances measured in the four circuits (the mechanical member may by analogy be referred to as a mechanical circuit) are:

$$Z_1 = D/D_{11},\ Z_2 = D/D_{22},\ Z_3 = D/D_{33},$$
$$Z_4 = D/D_{44} \quad (10)$$

Since all of the impedances are involved in these determinants, the driving point impedances Z_1, Z_2, Z_3, Z_4 are seen to depend on the reactions of all the circuits and the mechanical member.

The "damped" impedance of a receiver is the impedance of the coil measured with the diaphragm constrained from moving. This may be regarded as making the mechanical impedance infinite or "opening" the "mechanical circuit." The damped impedance of the system measured from circuit No. 1 is obtained

from the driving point impedance by suppressing row 4 and column 4. Designating the impedance measured in circuit No. 1 with No. 4 damped by Z_{1d4}:

$$\left.\begin{aligned} Z_{1d4} &= D_{44}/D_{11}{}^{44} \\ \text{Similarly } Z_{2d4} &= D_{44}/D_{22}{}^{44} \\ Z_{3d4} &= D_{44}/D_{33}{}^{44} \end{aligned}\right\} \quad (11)$$

These give the damped inpedances as measured from any of the three electrical circuits. These expressions also hold for the driving point impedance of the transformer, Fig. 2, equations **7**, with circuit No. 4 "opened."

The mechanical impedance of the vibrating member No. 4 under the influence of the reactions of circuits Nos. 2 and 3, but with No. 1 open, which by analogy can be called "damped mechanical impedance" is given similarly by

$$Z_{4d1} = D_{11}/D_{11}{}^{44}$$

Motional impedance is defined as the difference between the driving point impedance with the mechanical member free to move and with it damped.

$$Z_{1m4} = Z_1 - Z_{1d4}$$

In terms of the determinants of the system

$$Z_{1m4} = -\,D_{14}\,D_{41}/D_{11}\,D_{11}{}^{44}$$

This is typical of any electrical network as well and gives the effect on driving point impedance in any circuit No. 1, of any other circuit No. 4. In the case of the magneto-mechanical system $D_{14} = -\,D_{41}$.

$$\left.\begin{aligned} Z_{1m4} &= (D_{14})^2/D_{11}\,D_{11}{}^{44} \\ \text{Similarly} \quad Z_{2m4} &= (D_{24})^2/D_{22}\,D_{22}{}^{44} \\ Z_{3m4} &= (D_{34})^2/D_{33}\,D_{33}{}^{44} \end{aligned}\right\} \quad (12)$$

These give the motional impedances measured in any of the three electrical circuits.

In any invariable electrical, mechanical, or magneto-mechanical network, the driving point impedance Z_p measured from the p^{th} element, can be expressed as the sum of two terms, the first of which is independent of any other q^{th} circuit and the second of which is due to the reaction of the q^{th} circuit.

$$Z_p = Z_{pdq} + Z_{pmq}$$

Where

$$Z_{pdq} = D_{qq}/D_{pp}{}^{qq};\; Z_{pmq} = -\,D_{pq}\,D_{qp}/D_{pp}\,D_{pp}{}^{qq}$$

The first term may be called "damped" impedance and the second "motional" impedance.

The force per unit current in circuit No. 1 when the reactions of Nos. 2 and 3 are eliminated by "opening" is Z_{14}. A current in No. 1, however, induces currents in Nos. 2 and 3 which in turn act on No. 4 through their force factors Z_{24} and Z_{34} respectively. The total force acting on No. 4 is

$$Z_{14}\,i_1 + Z_{24}\,i_2 + Z_{34}\,i_3$$

A motion of the mechanical member causes modifying reactions on these currents producing a different force on this member than when constrained. By solving for the force resulting from unit current in circuit No. 1 after constraining No. 4 by suppressing row 4 and column 4 of the discriminant, it is found to be

$$\left.\begin{aligned} B_{1d4} &= D_{14}/D_{11}{}^{44} \\ \text{Similarly} \quad B_{2d4} &= D_{24}/D_{22}{}^{44} \\ B_{3d4} &= D_{34}/D_{33}{}^{44} \end{aligned}\right\} \quad (13)$$

These give the force per unit current in magnitude and phase with an electromotive force acting in circuits Nos. 1, 2 or 3 respectively as modified by induced currents in the other two circuits.

The electromotive force in circuit No. 1 per unit velocity of No. 4 is given by

$$\left.\begin{aligned} B_{4d1} &= D_{41}/D_{44}{}^{11} = -\,B_{1d4} \\ \text{Similarly} \quad B_{4d2} &= D_{42}\,D_{44}{}^{22} = -\,B_{2d4} \\ B_{4d3} &= D_{43}/D_{44}{}^{33} = -\,B_{3d4} \end{aligned}\right\} \quad (14)$$

This property holds generally for a "magneto-mechanical" network, and like that given above in contrast with the principle of reciprocity for invariable electrical and mechanical systems, is evident directly from the characteristic determinant by the fact that $D_{14} = -\,D_{41}$, $D_{24} = -\,D_{42}$, $D_{34} = -\,D_{43}$.

"The available force on a mechanical member per unit current in a circuit is equal in magnitude but opposite in sign to the available electromotive force in the same circuit per unit velocity of the same mechanical member."

In general, for an invariable electrical or mechanical network, or for a magneto-mechanical network,

$$B_{pdq} = D_{pq}/D_{pp}{}^{qq}$$

Motional impedance and the "damped" force factor B_{1d4} are therefore related by:

$$\left.\begin{aligned} Z_{1m4} &= \frac{(B_{1d4})^2}{Z_{4d1}} \\ \text{Similarly} \quad Z_{2m4} &= \frac{(B_{2d4})^2}{Z_{4d2}} \\ Z_{3m4} &= \frac{(B_{3d4})^2}{Z_{4d3}} \end{aligned}\right\} \quad (15)$$

Equations **15** give the most useful form for motional impedance.

The most useful substitutes for the general equations, No. 8, of motion are two in number, involving the current in the circuit in which the driving electromotive force acts and the velocity of the mechanical member on which a mechanical force may act.

$$\left.\begin{aligned} Z_{1d4}\,i_1 + B_{1d4}\,\dot{x} &= E_1 \\ B_{4d1}\,i_1 + Z_{4d1}\,\dot{x} &= F \end{aligned}\right\} \quad (16)$$

These correspond to equations No. 8 with currents i_2 and i_3 eliminated. They hold for invariable electrical and mechanical networks as well. Z_{1d4} is the apparent electrical impedance of the receiving coil and is independent of diaphragm motion. B_{1d4} is electromotive force generated in the coil per unit velocity, $\dot{x}$ of the diaphragm. B_{4d1} is force on the diaphramg per unit current in the coil and is equal to B_{1d4} in magnitude but opposite in sign. Z_{4d1} is the apparent mechanical impedance of the diaphragm. The reaction of the diaphragm in response to an applied

force is modified, both in magnitude and phase, by eddy currents.

Applications of the General Theory to Particular Receiver Structures

The application of the general theory to particular types of receivers consists in first showing the modification of the general structure, (Fig. 1) to which each corresponds, and modifying the characteristic equations (No. 5) accordingly. For example, if the simple receiver without eddy currents is to be studied the effects of circuits 2 and 3 are eliminated. In the equations the mutuals $Z_{12}, Z_{13}, Z_{23}, Z_{24}, Z_{34}$, or currents i_2, i_3, are placed equal to zero. The various types and discussions of their characteristics will be taken up separately.

A. Simple Receiver. The simple receiver is defined as one having no eddy currents in the core or diaphragm. This sort of receiver is never actually met with in practise but may be approximated by the use of high resistivity material or laminated cores and diaphragms.

The diaphragm of the receiver is not a mechanical element with one degree of freedom but may be so regarded without involving serious error. While vibrating, all parts of the diaphragm do not move with the same amplitude. The integrated product of surface density of the diaphragm and square of the velocity (r. m. s.) over the surface, gives the kinetic energy of vibration. The apparent vibrating mass, L_4 of the diaphragm is found by dividing the kinetic energy by the square of the velocity (r. m. s.) at the center. The shape of the curve of bending caused by the electromagnetic force acting about the center of the diaphragm varies with frequency of excitation, and hence, the apparent mass, L_4 must be considered as varying to a certain extent with the frequency. Similarly, the apparent elasticitance, C_4 is determined by the integrated potential energy of flexure which also varies with the frequency. The variation in L_4 and C_4 to be expected between the frequencies of zero and 3000 cycles is probably a matter of a 10 or 20 per cent gradual change for an ordinary receiver diaphragm. Similarly a variation in R_4 occurs in the receiver.

Attention must be called to the fact that even though L_4, C_4, and R_4 vary with frequency, they do not vary appreciably with amplitude of vibration at a single frequency for the small motions of a diaphragm. As a consequence, the law of superposition holds and the equations which have been deduced are valid. In complete theory, L_4, C_4, and R_4 should be replaced by their proper functions of frequency but since these changes are gradual they will not be included in this study of fundamental principles of the device.

The equations for the simple receiver are

$$\left.\begin{aligned} Z_{11}\, i_1 + Z_{14}\, \dot{x} &= E_1 \\ -\, Z_{14}\, i_1 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (17)$$

From these equations we find

$$i_1 = \frac{E_1 Z_{44} - F Z_{14}}{Z_{11} Z_{44} + Z_{14}^2}$$

$$\dot{x} = \frac{E_1 Z_{14} + F Z_{11}}{Z_{11} Z_{44} + Z_{14}^2}$$

These equations give either current or velocity re-

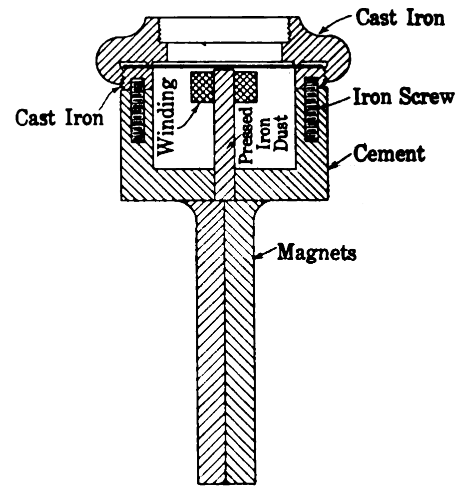


Fig. 3—Cross-Section of Experimental Receiver

sulting from an electromotive force acting in the winding as in a telephone receiver, or from a force acting on the diaphragm as in the case of a magnetic telephone transmitter, or a combination of both.

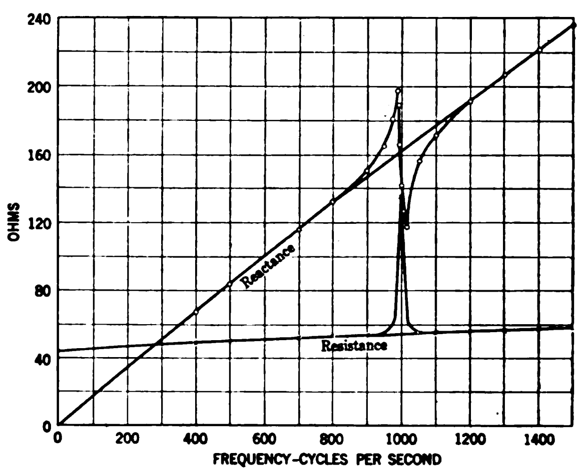


Fig. 4—Resistance and Reactance Curves of Experimental Receiver

The electrical impedance of the receiver is the ratio of the electromotive force acting to the resulting current in the coil and is given by

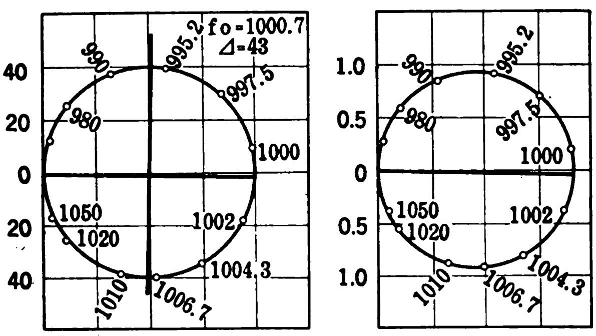
$$Z_1 = Z_{11} + Z_{14}^2 / Z_{44}$$

The damped impedance is simply the impedance of the coil Z_{11}, and the motional impedance is Z_{14}^2/Z_{44}. The "vector" locus of this motional impedance is a circle with its diameter coinciding with the real axis and tangent to the positive side of the imaginary axis.

Fig. 3 shows a cross-section of an experimental simple receiver. The pole piece was made of finely divided iron pressed together with shellac and energized by a pair of bar magnets. The cup was made of cement to reduce any possible eddy current effects and to minimize differential temperature expansions. The cap and seating surfaces for the diaphragm were cast iron. The diaphragm was a standard disk 0.009 in. thick. The coil had a resistance of 48 ohms and an inductance of 0.026 henry.

Fig. 4 shows plots of measured resistance and reactance of this receiver as functions of frequency. The eddy current effect is small as is shown by the relatively small increase in damped resistance, R, with frequency.

Fig. 5 shows the circular "vector" plots of measured motional impedance and computed velocity of motion of the center of the diaphragm at various frequencies in the region of resonance. The resonant frequency is seen to be 1000.7 cycles.



Motional Impedance Vector Plot Velocity Vector Plot

FIG. 5

The effective vibrating mass, L_4, of the diaphragm, is 0.68 gram as calculated from the observed change in natural frequency caused by adding a small known weight to the center of the diaphragm. The logarithmic decrement per second as determined from the motional impedance circle (Fig. 5) is $\Delta = 48$. The mechanical resistance, R_4, of the diaphragm obtained from the relation $\Delta = R_4/2\,L_4$ is 58.5 dynes per centimeter per second. At resonance of the diaphragm, $Z_{1m4} = b_{14}^2/R_4$. From this relation the force factor b_{14} was computed and found to be 2.18×10^6 dynes per absolute electromagnetic unit of current. The apparent elasticity $1/C_4$ of the diaphragm is 26.7×10^6 dynes per centimeter.

The mechanical impedance is the ratio of force F to velocity of motion, $\dot{x}$.

$$Z_4 = Z_{44} + Z_{14}{}^2/Z_{11}$$

Z_{44} is analogous to damped impedance because it is the impedance of the diaphragm when the electrical circuit is "damped" or "opened." Z_{14}^2/Z_{11} is analogous to motional impedance because it is the effect on the diaphragm of a "motion" of electricity in the coil. The "vector" diagram of this motional mechanical impedance is a semicircle and gives the damping effect of the circuit on the diaphragm at any frequency. If a condenser is placed in the circuit of the receiver coil the locus of Z_{14}^2/Z_{11} $(= Z_{4m1})$ is a circle exactly as in the case of Z_{1m4} but is given in mechanical units (mechanical ohms) instead of in electrical ohms.

The ratio of power dissipated in diaphragm motion to the total input is easily calculated. This ratio should not be confounded with the efficiency of the instrument as a telephone receiver because a large part of the power is dissipated in diaphragm friction as its supports and in air vibrations which do not reach the ear.

The mechanically dissipated power is *mod* $\dot{x}^2 R_4$, ("*mod*" is an abbreviation for modulus or "absolute" value). The input power is *mod* $i_1^2 R$ where R is total apparent resistance. The ratio e, at any frequency is

$$\begin{aligned} e &= mod\ (\dot{x}^2 R_4/i_1^2 R) \\ &= mod\ (Z_{14}^2 R_4/Z_{44}^2 R) \\ &= mod\ (Z_{14m4}^2/Z_{1M4} R) \end{aligned}$$

The symbol Z_{1M4} is used to denote the maximum motional impedance. At resonance, or the frequency of maximum response this reduces to

$$e_0 = mod\ Z_{1M4}/R$$

The theory of this receiver is the same as that of the vibration galvanometer.

B. Receiver with Eddy Currents in the Core. This receiver corresponds closely to the commercial instrument in which the effect of eddy currents in the diaphragm is usually small.

The theory of a receiver with eddy currents in the diaphragm only, as seen from the characteristic equations is identical with that to be considered here. A little consideration will make this apparent physically. When the diaphragm is damped an eddy current in the core obviously has the same qualitative effect as one in the diaphragm for they are coaxial. Similarly when the receiving coil, No. 1, is opened and the diaphragm moves toward the pole piece, an increase in magnetic flux in both circuits results. The damping effect on diaphragm motion is qualitatively the same due to either circuit.

We are regarding the eddy current in the core as a circuit. This is as well justified as regarding the diaphragm as a member of one degree of freedom. The principal body of eddy current flows around the core surface in a layer the thickness of which decreases roughly as the square root of the frequency. In an infinite cylindrical core inside of a solenoid the current distribution is a Bessel's function of the radial distance from the axis. Regarded as a circuit, the core eddy current consists of an elongated coil of one turn short-circuited on itself. The resistance to flow of eddy current is determined by the resistivity of the iron and the thickness of the layer. The resistance of the eddy current circuit, therefore, increases roughly as the square root of the frequency. Its inductance is fairly

constant since the flux linkage per unit current in this layer is about constant. At very low frequencies eddy currents are not confined to the surface, and the effective resistance and inductance of the eddy current circuit are, therefore, very small. The inductance approaches a constant value, as frequency increases, of the order of magnitude of the inductance of the receiving coil divided by the square of the number of turns.

In a common type of receiver having 700 turns per spool and 0.020-henry inductance, the inductance of the eddy current circuit would be of the order of $0.020/(700)^2$ or about 0.041×10^{-6} henry per pole. The eddy current circuit force factor, b_{24}, would be given, in order of magnitude, by that of the receiving winding divided by the number of turns, $5 \times 10^6/700$ or 0.71×10^4 dynes per absolute electromagnetic unit of current. As in the case of the diaphragm, the constants of the eddy current circuit vary with frequency, and to some extent with the character of the diaphragm motion, but do not vary appreciably with amplitude of current for the small values considered here.

The equations in this case are

$$\left.\begin{aligned} Z_{11}\, i_1 + Z_{12}\, i_2 + Z_{14}\, \dot{x} &= E_1 \\ Z_{12}\, i_1 + Z_{22}\, i_2 + Z_{24}\, \dot{x} &= 0 \\ -Z_{14}\, i_1 - Z_{24}\, i_2 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (18)$$

By eliminating i_2 these equations can be written

$$\left.\begin{aligned} (Z_{11} - Z_{12}^2/Z_{22})\, i_1 + (Z_{14} - Z_{24}\, Z_{12}/Z_{22})\, \dot{x} &= E_1 \\ -(Z_{14} - Z_{24}\, Z_{12}/Z_{22})\, i_1 + Z_{44} + (Z_{24}^2/Z_{22})\, \dot{x} &= F \end{aligned}\right\} \quad (19)$$

In terms of quantities already defined, these equations are identical with

$$\left.\begin{aligned} Z_{1d4}\, i_1 + B_{1d4}\, \dot{x} &= E \\ -B_{1d4}\, i_1 + Z_{4d1}\, \dot{x} &= F \end{aligned}\right\} \quad (20)$$

The form of these equations is similar to that of equations (**17**) for the simple receiver. Z_{1d4} corresponds to Z_{11}, B_{1d4} to Z_{14}, and Z_{4d1} to Z_{44}. The quantity Z_{1d4} or impedance of the receiver with the diaphragm constrained has been generally defined (equations **10**). Z_{4d1} is the apparent mechanical impedance of the diaphragm when the effect of the receiving coil is eliminated by "opening."

This shows how the receiver with eddy currents in the core can be treated by the same method used for a simple receiver by defining the coil, diaphragm and mutual impedances as proper functions of frequency. The motional impedance is given by

$$Z_{1m4} = B_{1d4}^2/Z_{4d1}$$

We will now compare the characteristics of these new parameters with those of the simple receiver. In the simple receiver the force factor, Z_{14}, is a constant. In this case it (B_{1d4}) varies with frequency.

$$B_{1d4} = b_{14} - b_{24}\,\frac{j\, w\, L_{12}}{R_2 + j\, w\, L_2} \quad (21)$$

Fig. 6 shows a schematic "vector" plot of the force factor, B_{1d4}, as dependent on frequency.

The locus is a semicircle below the real axis. At low frequencies the force factor is greatest approaching b_{14}, which is in phase with the current at zero frequency. At high frequency the force factor approaches the smaller value

$$b_{14} - b_{24}\, L_{12}/L_2$$

which is also in phase with current.

The motional impedance is given by

$$Z_{1m4} = (B_{1d4})^2/(Z_{44} + Z_{24}^2 / Z_{22}) \quad (22)$$

The locus of Z_{1m4} in a "vector" plot is not a circle. For circuit and diaphragm constants such as occur in most telephone receivers it is very nearly so, however. The character of the apparent mechanical impedance of the diaphragm Z_{4d1} as influenced by eddy currents can be shown best by its expansion. (Represent the modulus or absolute value of an impedance by z.)

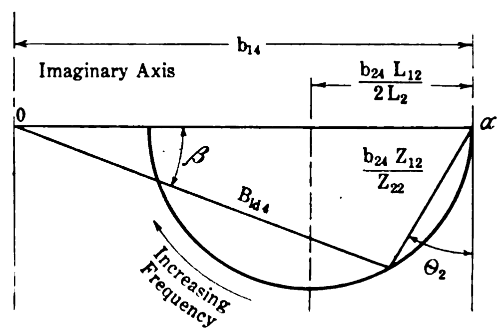


FIG. 6—SCHEMATIC "VECTOR" PLOT OF FORCE FACTOR

$$Z_{4d1} = \left(R_4 + R_2\,\frac{b_{24}^2}{z_2^2} \right) + j\, w \left(L_4 - L_2\,\frac{b_{24}^2}{z_2^2} \right) + \frac{1}{j\, w\, C_4} \quad (23)$$

The first term is the apparent mechanical resistance of the diaphragm. It is increased over the pure mechanical dissipative resistance R_4 by the addition of an eddy current component $R_2\, b_{24}^2/z_2^2$. This component decreases with frequency due to increase of z_2 with frequency.

The second term shows how the apparent mass of the diaphragm may be regarded as being decreased by the influence of eddy currents. The effect is to modify the mechanical reactance in such a way as to increase the frequency of maximum response. The decrease in apparent mass becomes less as the frequency of excitation is increased due to the variation of z_2.

The "vector" plot of the reciprocal of Z_{4d1} is not strictly a circle because of the variation of its real component with frequency. Variation of z_2 with frequency through the range of resonance of a receiver diaphragm is small enough to make the deviation from circular form inappreciable. The variation of the reactive terms has no influence on this circular form

of motional impedance. They determine only the distribution of points about the circumference of the circle and therefore lead to errors in the calculation of logarithmic decrement per second by the standard method from resonance circles or curves. The errors are only serious when the resonant region is large.

The variation in force factor B_{1d4} with frequency due to the term $b_{24} Z_{12}/Z_{22}$, representing the eddy current reaction, also produces a small deviation from circular form in motional impedance. This term shows how the eddy current produces a depression in the principal diameter of the motional impedance circle. This depression angle 2β, Fig. 6, is twice the angle of B_{1d4}. Since β is a function of frequency the angle of depression 2β, of motional impedance, is a function of the frequency to which the diaphragm is tuned, being small at low frequencies, higher at intermediate frequencies, and small at very high frequencies.

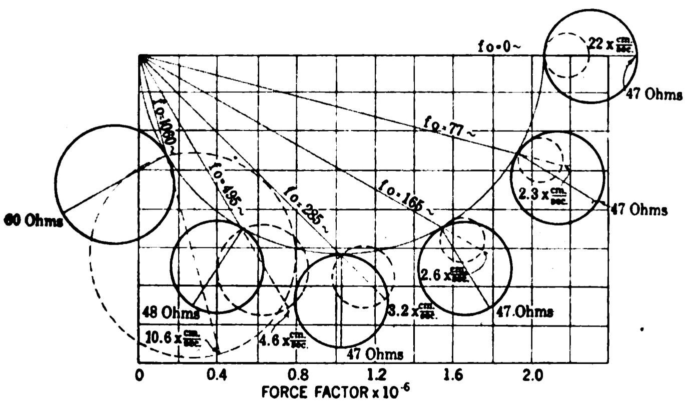


Fig. 7—Force Factor, Motional Impedance and Velocity at Different Frequencies

Velocity given per milliampere—dotted circles.

To illustrate the variation of force factor and motional impedance in this type of receiver, a simple case shown in the diagram (Fig. 7) was computed.

The constants of the experimental receiver were used with the exceptions that no mechanical resistance R_4 was assumed in the diaphragm and in place of eddy current in the core, a second winding was assumed of the same constants as the receiving coil completely coupled to it and short-circuited. In this case the force factor semicircle has a diameter of b_{14}. Motional impedance circles with the diaphragm tuned to six different frequencies are shown in heavy lines at the ends of their corresponding force factor "vectors." The frequencies of tuning are 0, 77, 165, 285, 495, and 1060 cycles. The circles increase in diameter with frequency of tuning of the diaphragm. This is because the eddy current component of damping resistance decreases at a faster rate than B_{1d4}. The dotted circles are corresponding "vector" diagrams of root mean square velocity of the diaphragm per milliampere of current in the winding. These increase in diameter indefinitely with frequency. In practise, these circles may either increase or decrease with frequency of tuning depending upon the relative magnitudes and variations of R_4, B_{1d4}, and eddy damping reaction $R_2\, b_{24}^2/z_2^2$.

The force factor semicircle can be determined experimentally for any receiver. The value of B_{1d4} is found in phase and magnitude at resonance from the motional impedance circle, or resonance curve, by a method such as that given under "Simple Receiver." By reference to Fig. 6, it will be seen that the additional measurement of the angle θ_2 determines the semicircle. The angle θ_2 is the phase angle of the eddy current circuit at the frequency of diaphragm resonance and is found from the damped impedance by the following reasoning.

$$Z_{1d4} = (R_1 + R_2\, z_{12}^2/z_2^2) + j\, w\, (L_1 - L_2\, z_{12}^2/z^2) \qquad \textbf{(24)}$$

At low frequencies the apparent resistance and inductance approach the values R_1 and L_1. These may be determined by extrapolation from measurements of damped impedance at low frequencies. The differences between the damped resistance and inductance at resonance and these values give the last terms in these two parentheses. The ratio of the differences give, $\tan \theta_2 = w\, L_2/R_2$. Having found the semicircle, the force factor B_{1d4} can be found at any frequency by simply measuring θ_2 in this way from the damped impedance, drawing a line from "a" (Fig. 6) at this angle. The line connecting its intersection with the semicircle and the origin is the force factor at the frequency in question.

A variation in inductance L_2 of the eddy circuit will cause a deviation from the circular form of the force factor locus through the speech range of the frequencies and above it. The eddy circuit inductance is usually very nearly constant in commercial receivers. The variation in the resistance R_2 of the eddy circuit alters the simple theoretical distribution of points about this locus. R_2 increases indefinitely with frequency. This tends to retard the progress of the force factor around this locus as frequency increases. In one type of receiver investigated with a single cylindrical core, the eddy current resistance approaches linear increase with frequency such that the eddy current phase angle θ_2 approaches a constant value of about 70 deg. instead of 90 deg. at high frequencies.

To illustrate the application of this theory, an analysis of a particularly efficient standard bipolar head receiver was made. It is assumed that the coils and eddy currents in the two poles are approximately the same. This allows of treating two eddy circuits as one. Fig. 8 shows curves of measured resistance and reactance plotted as functions of frequency from 0 to 1500 cycles. The distortion of these curves from a smooth variation in the neighborhood of 1000 cycles is due to a large vibration of the diaphragm in the region of its natural frequency. In a small region between 1000 and 1050 cycles, the vibration of the diaphragm is in such a phase and large enough actually to give the receiver as a whole an effective capacity reactance.

The smooth curves are drawn asymptotically and represent to a fair accuracy the "damped" values which would be obtained by restraining diaphragm motion. The circular "vector" plot of motional impedance is given in Fig. 9. The frequency of the maximum response of the diaphragm is 1005 cycles, at which the

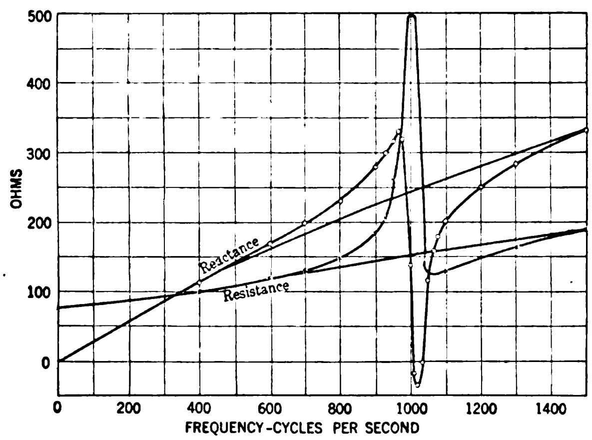


Fig. 8—Standard Bipolar Head Receiver—Resistance and Reactances Curves

motional impedance is $332 - j\,180$ or 380 ohms at an angle 2β of $-$ 28.5 deg. The logarithmic decrement per second, of the diaphragm is 138. This is obtained from the circle by multiplying the difference between the frequencies at opposite ends of the diameter perpendicular to the principal diameter of the motional impedance circle by π.

The apparent mass of the diaphragm $(L_4 - L_2\, b_{24}^2/z_2^2)$ is 0.400 gram. This is found by a calculation from the measured change in frequency of maximum response by the addition of a small known mass at the center of the diaphragm. The resistance to motion of the

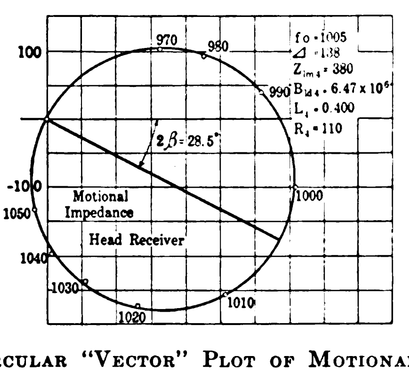


Fig. 9—Circular "Vector" Plot of Motional Impedance

diaphragm $(R_4 + R_2\, b_{24}^2/z_2^2)$ is 110 dynes per centimeter per second and is found from the relation

$$\Delta = (R_4 + R_2\, b_{24}^2/z_2^2)/2(L_4 - L_2\, b_{24}^2/z_2^2)$$

The motional impedance is given by

$$Z_{1m4} = B_{1d4}^2/(Z_{44} + Z_{24}^2/Z_{22})$$

(see equation 22), which owing to the cancelling of the mass and elastic reactances of Z_{44} becomes at the frequency of maximum response

$$Z_{1m4} = B_{1d4}^2/(R_4 - R_2\, b_{24}^2/z_2^2)$$

From this, the damped force factor B_{1d4} was computed at the frequency of maximum response to be $(6.28 - j\,1.59) \times 10^6$ or 6.47×10^6 dynes per absolute electromagnetic unit of current, at an angle of $-$ 14.3 deg. This is plotted "vectorially" in Fig. 10, the reference phase being that of i_1, the current in the receiving winding. The semicircle given in this figure is the locus of B_{1d4} as frequency is varied. The force factor at zero frequency, b_{14}, is 8.44×10^6 and is in phase with the received current. The semicircular locus was determined by the method given in the discussion of equation **21**. The force factors at 500 and 1500 cycles are also given.

The part of the resistance due to eddy current $(R_2\, b_{24}^2/z_2^2)$ is computed to be 42 dynes per centimeter per second which is about 38 per cent of the total. The eddy current component of resistance is computed from the force factor diagram, Fig. 10, and damped

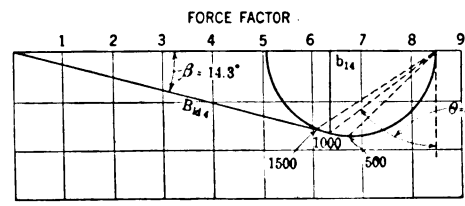


Fig. 10—Head Receiver-Plot of Force Factor B_{1d4}

impedance, Fig. 8. A little calculation will show that this is equal to the product of the real and imaginary components of the "vector," $-\, b_{24}\, Z_{12}/Z_{22}$ of the experimentally determined force factor diagram (of Fig. 6) divided by $w\, L_2\, z_{12}^2/z_2^2$ obtained from damped reactance (see discussion of equation **24**).

The apparent mass of the diaphragm is 0.400 gram. This is less than the purely mechanical apparent mass by 0.009 gram or about 2 per cent which gives an increase in maximum response frequency of about 10 cycles. The eddy current component of apparent mass can be seen to be equal to the product of the real and imaginary parts of the "vector" $-\, b_{24}\, Z_{12}/Z_{22}$ in the force factor diagram divided by the product of the radial frequency w, and the added damped resistance $R_2\, z_{12}^2/z_2^2$ due to eddy currents (see equation **24**).

C. Simple Induction-Type Receiver. In principle, an ordinary telephone receiver using a non-magnetic conducting diaphragm such as aluminum or copper is an inefficient induction receiver. The most familiar example of a device working on this principle is the Fessenden submarine oscillator. Motion of the diaphragm causes no change of inductance of any circuit except the eddy current circuit on the diaphragm which moves with it. This circuit is No. 3 in Fig. 1. As a consequence, $b_{14} = b_{24} = 0$. b_{34} is therefore the only acting force factor.

Excluding all eddy currents other than that in the diaphragm, the characteristic equations are

$$\left.\begin{aligned} Z_{11}\, i_1 + Z_{13}\, i_3 \qquad\quad &= E_1 \\ Z_{13}\, i_1 + Z_{33}\, i_3 + Z_{34}\, \dot{x} &= O \\ - Z_{34}\, i_3 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (25)$$

Eliminating i_3

$$\left.\begin{aligned} (Z_{11} - Z_{13}^2/Z_{33})\, i_1 + (- Z_{34}\, Z_{13}/Z_{33})\, \dot{x} &= E_1, \\ - (- Z_{34}\, Z_{13}/Z_{33})\, i_1 + (Z_{44} + Z_{34}^2/Z_{33})\, \dot{x} &= F \end{aligned}\right\} \quad (26)$$

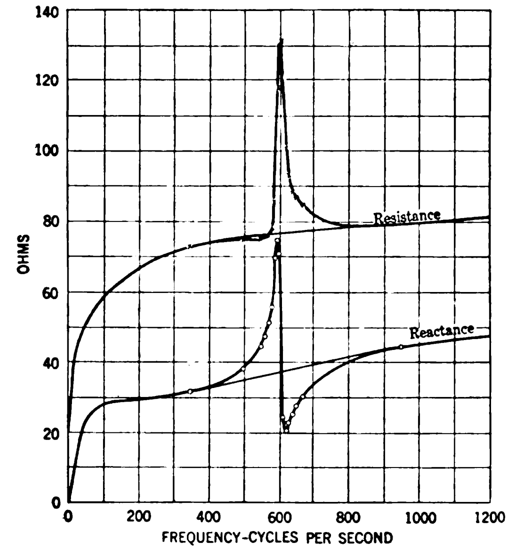


FIG. 11—INDUCTION-TYPE RECEIVER—RESISTANCE AND REACTANCE CURVES

Following the reasoning given under "*B. Receiver with Eddy Currents in the Core.*" These equations are identical with

$$\begin{aligned} Z_{1d4}\, i_1 + B_{1d4}\, \dot{x} &= E_1 \\ - B_{1d4}\, i_1 + Z_{4d1}\, \dot{x} &= F \end{aligned} \quad (27)$$

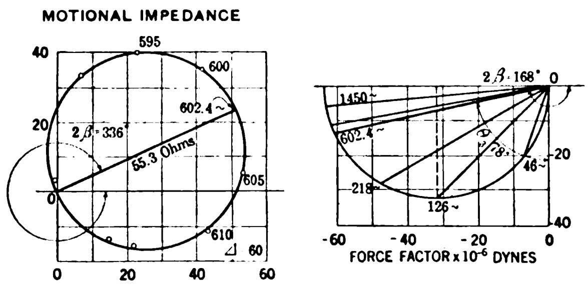


FIG. 12—INDUCTION-TYPE RECEIVER—MOTIONAL IMPEDANCE AND FORCE FACTOR DIAGRAMS

These are the equations of the induction-type receiver reduced to the form of the simple receiver. As before the motional impedance is given by

$$Z_{1m4} = B_{1d4}^2/Z_{4d1}$$

The forms of Z_{1d4} and Z_{4d1} are identical with the former case and the same discussion holds here. The force factor B_{1d4} and the motional impedance Z_{1m4} are somewhat different.

Fig. 11 shows the curves of measured resistance and reactance as a function of frequency for an experimental induction-type receiver. The smooth asymptotic curves represent damped values.

Fig. 12 shows the motional impedance and force factor diagrams of this receiver at different frequencies.

The force factor for an induction-type receiver is given by

$$B_{1d4} = - b_{34}\, \frac{j\, w\, L_{13}}{R_3 + j\, w\, L_3} \quad (28)$$

By comparison with equation **21**, it will be seen that this has the same semicircular form as the force factor

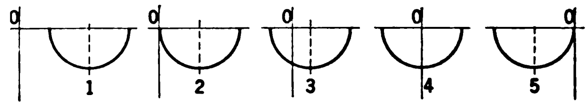


FIG. 13—POSSIBLE FORCE FACTOR SEMICIRCLES

for a receiver with eddy currents in the core, but is displaced on the real axis to a point of tangency on the negative side of the imaginary axis. This is due to the absence of the direct force factor, b_{14}, between the receiving winding and the diaphragm. In order for this type of receiver to be efficient, the semicircle must be large, and the phase angle, θ_3, of circuit No. 3 must be large. This means that R_3 must be small.

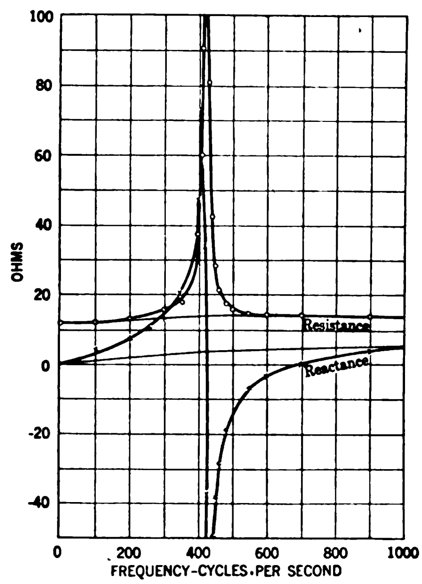


FIG. 14—ELECTRODYNAMIC RECEIVER—RESISTANCE AND REACTANCE CURVES

The force factor is determined experimentally by the same method as that used in the previous case "B".

The angle, 2β, of maximum motional impedance is 336 deg. and that of the force factor at this frequency is $\beta = 168$ deg. at the frequency, 602.4 cycles, of resonance. The phase angle of circuit No. 3 is $\theta_3 = 78$ deg. at resonance. The theory of this apparatus when used to receive mechanical energy is obtained from the equations by allowing the vibrating force F to act instead of the electromotive force E_1.

It is interesting to note that the theory of this system is the same as that for the simple receiver

(without eddy currents) but working through a transformer.

The force factor semicircles of cases "B" and "C" are in a sense closely related.

$$B_{1d4} = Z_{14} - Z_{24}\, Z_{12}/Z_{22}$$

This is the equation of the force factor for case "B". By changing the relative values of the first and second terms, the semicircle representing it is moved along the real axis from any position on the positive side (Z_{14} larger), down through a point of tangency on the positive side of the imaginary axis as in Fig. 6 to tangency on the negative side which corresponds to the induction-type receiver in which case $Z_{14} = 0$. Fig. 13 illustrates a series of possible force factor circles with one circuit in addition to the receiver circuit, No. 1.

Diagram 1. $b_{14} > b_{24}\, L_{12}/L_2$

This is the case in which the eddy current is least. If the semicircle shrinks to a point we have a case of a simple receiver.

Diagram 2. $b_{14} = b_{24}\, L_{12}/L_2$

For this condition it is necessary that circuits Nos. 1 and 2 have 100 per cent inductive coupling. Fig. 7 illustrates this case.

Diagram 3. $b_{24}\, L_{12}/L_2 > b_{14} > b_{24}\, L_{12}/2\, L_2$

This is the first case in which the phase of the force factor can be greater than 90 degrees.

Diagram 4. $b_{24}\, L_{12}/2\, L_2 = b_{14}$

The magnitude of the force factor here is independent of frequency but its phase increases from zero to $-$ 180 deg.

Diagram 5. $b_{14} = 0$

This is the case of the induction-type receiver, or simple receiver, working through a transformer.

D. Electrodynamic Receiver. The electrodynamic receiver operates by placing the driving coil on a movable member or diaphragm which is non-magnetic. Referring to Fig. 1, this case corresponds in principle to using coil No. 3 as the receiving coil. The theory of this case is identical with that for the vibration galvanometer which corresponds to a simple receiver if no eddy currents are present.

We will consider the case where an eddy circuit No. 2 is present in the stationary magnetic poles supplying the polarizing flux. The characteristic equations are

$$\left.\begin{aligned} Z_{22}\, i_2 + Z_{23}\, i_2 \qquad\qquad &= 0 \\ Z_{23}\, i_2 + Z_{33}\, i_3 + Z_{34}\, \dot{x} &= E_3 \\ - Z_{34}\, i_3 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (29)$$

This is different from the induction-type receiver, case "C," only in that the driving electromotive force acts in circuit No. 3 instead of the stationary circuit. In this case we are interested in the impedance measured from circuit No. 3.

Eliminating i_2

$$\left.\begin{aligned} (Z_{33} - Z_{23}^2/Z_{22})\, i_3 + Z_{34}\, \dot{x} &= E_3 \\ - Z_{34}\, i_3 + Z_{44}\, \dot{x} &= F \end{aligned}\right\} \quad (30)$$

As before the coefficient of i_3 in the first equation is the damped impedance Z_{3d4} of the receiver. The force factor is independent of frequency and uninfluenced by the eddy current. The motion of the diaphragm is independent of eddy current which adds no electromagnetic damping.

$$Z_{3m4} = Z_{34}^2/Z_{44}$$

Motional impedance as in the case of the simple receiver is represented by a circle with its principal diameter coinciding with the real axis as in the case of the simple receiver. Eddy currents act simply as an inductively coupled external circuit.

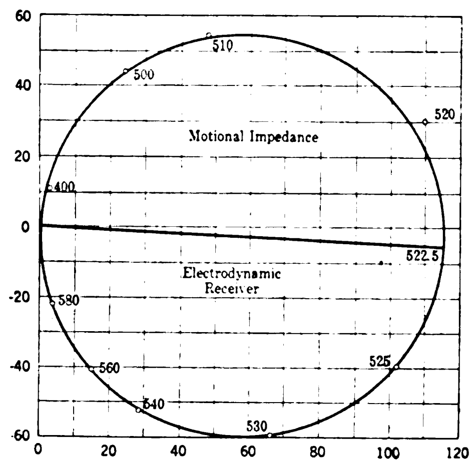


Fig. 15—Vector Plot of Motional Impedance

Fig. 14 shows plots of measured resistance and reactance of such a receiver. Fig. 15 is a vector plot of motional impedance. The natural frequency is 522.5 cycles. The depression angle of maximum motional impedance is small due to a small effect of eddy current in the coil supports on the diaphragm.

Conclusion

The object of this paper is to reduce the theory of typical magneto-mechanical vibratory structures to the simplicity of the electrical network theory, which amounts essentially to a manipulation of complex algebra.

The method is illustrated by experimental data on representatives of the leading types of magnetic receivers and transmitters. It is equally applicable to types having any number of circuits or mechanical vibratory systems including electromagnetic galvanometers and meters.

Rates for Electrical Energy and Service

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WITH the fact that nearly 500 bituminous coal mines in this vicinity are served wholly or in part by central station power service, this discussion of power rates has been prepared principally for the A. I. M. E. members, assuming that the members of the A. I. E. E. section of this joint meeting are more or less familiar with the various forms of rate schedules.

It is about as impossible to frame a power rate exactly correct for each consumer as it is for a life insurance company to name an exact rate (based on cost) for each risk that it assumes. Rates are necessarily based upon classifications, diversity factors and averages as well as costs of production. When the entire output is taken by one consumer an exact rate is a simple matter, but when thousands of consumers, distributed over a hundred or more square miles of territory, are served under all sorts of conditions, the preparation of equitable rate schedules is quite another matter.

An ideal schedule, especially for small consumers, would be one so simple that the purchase of service could be as easily made as visiting the grocery for staple articles. Most power schedules, even those available to small users, are so bewildering to the layman as to frequently breed distrust in their fairness and the "conscientious objectors" are generally more numerous among the smaller users.

The "straight line" meter rate, which is the simplest form of meter rate, has a constant unit price per kilowatt-hour, which does not vary on account of an increase or decrease in the number of units used, hence the average price is shown by a straight horizontal line. This form of rate schedule is generally confined to residence and small commercial business which carries a minimum monthly charge of 50 cents to $1.50.

The "step" meter rate is one in which the entire consumption is billed at a single price, which depends upon the particular "step" within which the total consumption falls. It is generally expressed as follows:

10	cents per kw-hr. for	1 to 20 kw-hr.
8	" " " "	21 " 40 "
6	" " " "	41 " 100 "
5	" " " "	101 " 200 "
3	" " " "	more than 200 kw-hr.

The curve of operation of this form of schedule is shown in Fig. 1 and it is apparent at a glance that very slight variations in consumption will often create very material differences in unit prices and total bills, for instance, 180 kw-hr. at 5 cents = $9.00 and 210 kw-hr. at 3 cents = $6.30, an increase in consumption of one-sixth, reducing that total bill by 30 per cent. This form of rate has the further disadvantage of not being based upon load factor, which is a vital factor in costs.

The "block" meter rate provides a price or charge for any part or all of certain specified blocks of consumption, with reduced prices per kw-hr. for each succeeding block or any portion thereof. This rate is as easily understood by consumers as the step rate and it avoids the wide variations in prices and total bills, with relatively small differences in consumption, which is characteristic of the step rate. The influence of load factor on costs is ignored, but this defect is often corrected by providing a demand or ready-to-serve charge,

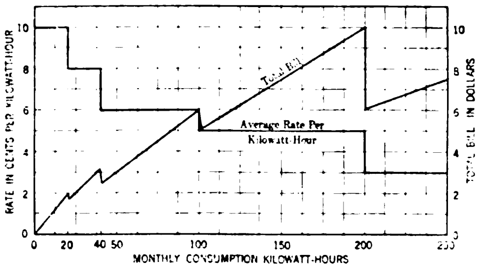

FIG. 1—STEP METER RATE

in addition to the energy charge, this combination method being known as the Hopkinson demand rate. The ordinary block rate is generally expressed as follows:

10	cents per kw-hr. for the first	20 kw-hr.
8	" " " " " next	20 "
6	" " " " " "	60 "
5	" " " " " "	100 "
3	" " " "	all excess over 200 kw-hr.

The bills under the block rate are figured as follows:

20 kw-hr.	at 10 cents	=	$2.00
20 "	at 8 "	=	1.60
35 "	at 6 "	=	2.10
			$5.70

The average price paid under this bill is 7.6 cents per kw-hr.

The following block rate schedule is in use by an Ohio central station and this form of general power schedule is commonly used by smaller utilities.

5	cents per kw-hr. for	1 to 200 kw-hr.
4.5	" " " "	201 to 350 "
4	" " " "	351 to 550 "
3.5	" " " "	551 to 800 "
3	" " " "	801 to 1800 "
2.5	" " " "	1801 to 2500 "
2.25	" " " "	2501 to 3500 "
2	" " " "	3501 or over "

Presented at the combined meeting of the Pittsburgh Sections of the A. I. E. E. and A. I. M. E., Pittsburgh, Pa., January 21, 1921.

One consumer with a 5-h. p. motor (4.5 kw. demand) operating 200 hours per month at 80 per cent average load will use about 720 kw-hr. with a load factor of about 22.2 per cent, while another consumer with a 15-h. p. motor (13-kw. demand) often uses a similar amount of energy, with a load factor of about 7.7 per cent, both consumers paying identical unit and total costs for the service. The 15-h. p. consumer should

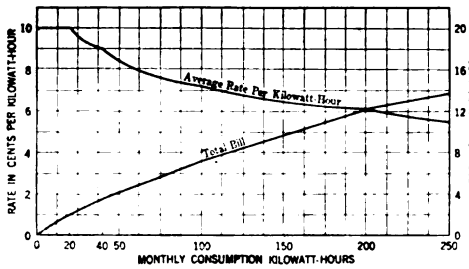

Fig. 2—Block Meter Rate

pay (based on a load factor cost basis) between 2 and 2.5 times the rate per kw-hr. that the 5-h. p. user should pay. This schedule probably yields a proper average return from the total power business, but it does not provide the proper relative returns from the high and low factor consumers.

The term "demand rate" is given to a method of charge which is based upon the capacity of a consumer's installation or his maximum demand, expressed in kilowatts or horse power (which may be either estimated or measured) during a given period of time, usually a month or a year.

The term "flat demand rate" is given to a charge for service based upon the user's installation of energy-consuming devices and is frequently modified by the "step" or "block" method. It is frequently used for residence service and is expressed as follows:

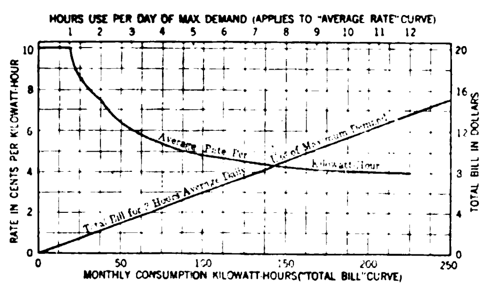

Fig. 3—Wright Demand Rate

$2.00 per month per 100 watts connected load, or
25.00 per year per horse power of connected load, or
50.00 per year per kw. for the first 25 kw. of demand.
30.00 per year per kw. for the excess above 25 kw.

The "Wright demand rate" is a method in which a maximum unit price is charged for a given amount of energy, with several reduced charges (on the block principle) for additional energy supplied, the rates being based upon the use of the maximum demand (load factor basis) which may be either estimated or measured. This rate schedule is generally applied to the larger commercial lighting and power users and is expressed as follows:

10 cents per kw-hr. for the first 30 hr. use of the demand.
6 cents per kw-hr. for the next 30 hr. use of the demand.
4 cents per kw-hr. for all energy in excess of 60 hr. use of demand.

The bill for a consumer having 10 kw. of demand and a consumption of 750 kw-hr. (equivalent to 75 hours' use of the demand) is prepared as follows:

300 kw-hr. (30 hours × 10 kw.)	at 10 cents	=	$30.
300 " "	at 6 "	=	18.
150 " "	at 4 "	=	6.
			$54.00

The average price per kw-hr. of energy used is 7.2 cents. The operation of this schedule is shown in Fig. 3.

The "Hopkinson demand rate" method consists of a demand charge to which is added an energy charge

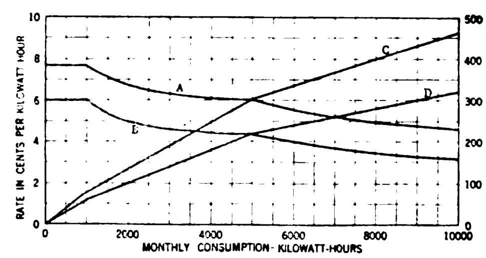

Fig. 4—Block Hopkinson Demand Rate

based upon metered energy used. The demand charge is generally based on the connected load for small installations and upon a measured demand for large installations. This rate schedule is expressed as follows:

Demand Charge:
$2.40 per kw. per month for 50 or less kw. of demand.
2.00 per kw. per month for the excess over 50 kw. of demand.
Energy Charge:
5 cents per kw-hr. for the first 100 kw-hr. used.
3 cents per kw-hr. for the next 4000 kw-hr. used.
1 cent per kw-hr. for the excess over 500 kw-hr. per month.

The bill for a consumer having 100 kw. of demand and an energy consumption during the month of 7000 kw-hr. is prepared as follows:

Demand Charge:		
50 kw. at $2.40 =	$120.	
50 kw. at $2.00 =	100.	
		$220.00
Energy Charge:		
1000 kw-hr. at 5 cents =	$50.	
4000 kw-hr. at 3 " =	120.	
2000 kw-hr. at 1 " =	20.	
		$190.00
7000 kw-hr.	Total Bill	$410.00

The average price per kw-hr. of energy used is about 5.86 cents.

The operation of this schedule is shown in Fig. 4.

Curve *A* is the average rate per kw-hr. for 3 hours average daily use of the maximum demand and curve *B* is the same data for 8 hours use. Curves *C* and *D* show respectively the total bills for 3 hours and for 8 hours use of the demand.

The "Doherty rate," or "three charge rate" (proposed in 1900 by Mr. Henry L. Doherty) is a method consisting of a customer's charge ($1.00) per month per meter) plus a demand charge, plus an energy

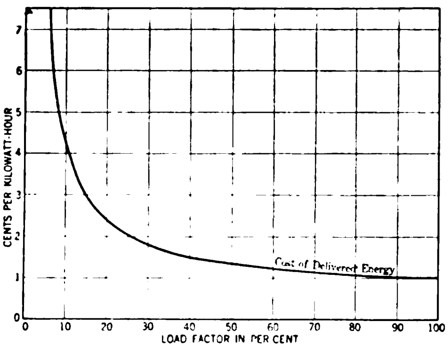

FIG. 5—COST OF DELIVERED ENERGY

charge for metered energy supplied. This form of schedule is not used in this vicinity, hence an explanation of it will not be made.

There is a tendency to question the merits of the "service-at-cost" method of rate fixing, which has been but little used in rates other than railway fares. The recent public statement of Mr. E. I. Lewis, Chairman of the Indiana Public Service Commission, is indicative of this tendency. The writer is of the opinion that it will not nor should not find any but very limited application in light and power rates.

Application has been recently made to the West Virginia Public Service Commission for the use of Zone rates for the purpose of "equalizing" the rates for electricity by providing an additional charge, for all consumers outside a given area, to compensate for additional expenses of transmission. This is an unusual method and is not likely to find very general approval, application or use even for very large and widely extended systems.

In most states the income of the utility from municipal street lighting service is given little or no consideration in connection with questions of commercial and domestic rates, this income being treated as a "voluntary" rate of the company (which the commission cannot change) and whether the contract is a source of profit or loss is not pertinent to the question of the resonableness of other rates.

A general or large power rate schedule should be based upon and conform to a load factor cost curve. From records of annual kw-hr. output through plant switchboard, kw-hr. accounted for by consumers' meters, station load factor, investment or property valuation and operating expenses, an average delivered cost curve, for all load factors, can be readily constructed. The rate of return on the investment or valuation and minor items, such as taxes and insurance, enter into the calculations, depreciation being made part of operating expenses.

The curve, Fig. 5, shows the relation of the cost of delivered energy to load factor, assuming, for convenience, that the cost of service at 100 per cent load factor is one cent. The "curve" from 75 per cent to 100 per cent load factor is almost exactly a straight line, the cost at 75 per cent being 1.119 of that at 100 per cent load factor. The cost of service at 50 per cent load factor is 1.357 that at 100 per cent and 1.213 that at 75 per cent load factor. Below 50 per cent the curve rises more sharply and the cost at 25 per cent load factor, which is fairly representative of a bituminous coal mine in this vicinity, is 1.525 that at 50 per cent load factor. The relation of costs at various other load factors is readily ascertained by reference to the curve.

Load factor expressed in hours use of demand is as follows:

Hours use per day	Equivalent Load Factor	Hours use per day	Equivalent. Load Factor
1	4.2%	13	54.3
2	8.3	14	58.3
3	12.5	15	62.5
4	16.6	16	66.6
5	20.8	17	72.
6	25.	18	75.
7	28.2	19	78.
8	33.3	20	84.
9	37.5	21	88.
10	41.7	22	92.
11	45.8	23	96.
12	50.	24	100.

The shape of this curve is derived from an annual revenue of 25 per cent of the investment or valuation, operating expenses at 60 per cent of the revenue, a return of 8 per cent on investment, reserves and surplus of 2 per cent of investment, one hour station peak loads of 80 per cent of plant capacity, a load factor of 50 per cent based on one hour peaks and 85 per cent of the output through station switchboard accounted for by consumers' meters.

The effect of "load factor" on the cost of production of coal (your own product) should be familiar to those in contact with mine operation cost accounts. Some of you have probably made estimates or "dreamed dreams" of what your production costs should or could be with a 100 per cent car and labor supply, a few pages of unfilled orders always ahead of you and 300 to 310 working days per year, in other words an 80 per cent to 85 per cent load factor, based on 365 days.

A mine has this advantage on "demand"; a large demand for coal for shipment tomorrow will be met

by shipping your output and the unfilled remainder may go forward the next day, or the next, or you may buy a few cars and fill out the order, the consumer meanwhile has a few days stock on hand. When you throw in the switches on your motors on hoists, fans, pumps, locomotives, tipples, mining machines, etc., all the power that you need must be delivered at that instant and for as long as you need it. You will pardon this garrulous remark, but the power company cannot ship you a "load of assorted amperes and volts" today and promise you another car tomorrow, and you have none in stock "to hang on your trolley wire."

In several power rate schedules, which the writer has analyzed, the demand or readiness-to-serve charge set up was found to be low in proportion to the total price paid for the service, resulting in a rate more favorable to the low load-factor consumer. In several sliding scale demand rates, which I have had occasion

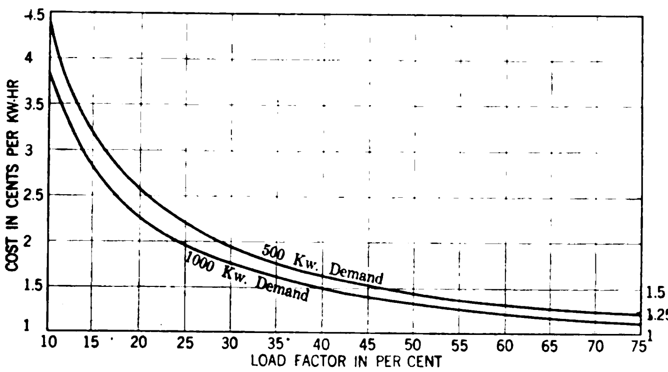

FIG. 6—SCHEDULE "J" RATES

to examine, the variation of price per kw., between small and large demands, did not run even approximately true to the actual variations in cost of readiness-to-serve. Large power schedules generally provide for a measured demand, for an interval of 5 or 15 minutes or one hour.

Most large power rate schedules specify a demand charge and an energy charge (in addition to the demand charge), but the same total prices for service at various load factors can be made, without the use of a separate demand charge, by means of a relatively high rate for the "primary" block of energy used and a low rate for the secondary or tertiary blocks of energy. An example of this method is afforded by Schedule "J" of the West Penn Power Co., with which many of you are already familiar. This schedule provides a charge of 6 cents gross per kw-hr. for the first 70 hours use of the demand and 1¼ cents gross per kw-hr. for all energy in excess of the first 70 hours use, with block discounts of from 2½ per cent to 43 per cent. The operation of Schedule "J" for a demand of 500 kw. and for 1000 kw. is shown in the curve, Fig. 6.

Where the franchise limitations of the maximum permissible rate for power service give a rate which is below the cost of low load-factor service, a minimum bill is sometimes set up which will assist in avoiding a loss or a discrimination in favor of the low load-factor consumer. It often occurs that a utility is compelled, by its inability to name equitable rates for low load-factor users, to discriminate in its rate schedules against the high load-factor user, which is its most desirable business.

Most large power schedules penalize low power factor of the consumer's service. Some provide that the average power factor shall be the basis although the detriment occasioned by low power factor is almost invariably greatest during peak hours, the effect of low power factor at other hours being localized. The recording of the time and periods of low power factor and the complications and expense of figuring bills have led to the adoption of the average power factor as the commercial basis in rate schedules. Lightly loaded induction motors are generally the source of low power factor, and it often pays, on installations of any considerable size, to provide for power factor correction where penalties are attached to rate schedules.

Power rate schedules of one large utility provide that, for demands of more than 100 kv-a., a correction factor (on the kw-hr. used) shall be applied for average power factors above and below 85 per cent for the month.

Effective P. F.	Constant	Effective P. F.	Constant.
100	0.951	80	1.023
95	0.965	75	1.05
90	0.981	70	1.0835
85	1.000	65	1.125

This method has several advantages and provides a penalty for less than 85 per cent power factor and a bonus for power factors above 85 per cent which, in my opinion, is the proper power factor in most cases for general application of unity meter registration in large power schedules.

In large power schedules, provision is sometimes made for a special and lower rate in consideration of the privilege of temporarily interrupting the service to the consumer in event of shortage of power. Many of you will probably realize the impracticability in most cases of controlling the service to certain users supplied from a large network of power circuits. A provision of this character often amounts to a special concession and a discriminatory rate, with the privilege of disconnection as an apparently plausible excuse.

The terms and conditions of contract are often but little less in importance than the rates themselves. The inclusion of instantaneous peak ratings, kv-a. rating penalties for even relatively high power factors, often results in considerable increases in the cost of service at given unit rates for demand and energy. The subject of terms and conditions of contract is too broad and complicated to discuss at this time.

There are numerous variations and combinations of the typical rates outlined above, also many methods of determining the amount of the maximum demand and of making a charge for it. A Wright demand schedule sometimes contains eight or ten steps of ratings, between 10 and 500 h. p. Straight line meter rates may be modified by several steps of discounts or reduced charges which vary with guaranteed minimum bills. Any of the various typical rates may carry 3 or 6 or 10 or any number of discounts. A block rate schedule may carry a list of 8 or 10 load-factor discounts. There are many minds at work on rate schedules and many conditions to be met, hence the numerous forms of schedules and of terms and conditions of contract.

The voltage regulation of the supply circuit often has a bearing on the cost and quality of the power service; for instance, kv-a. peaks (sometimes the basis of demand charges) are accentuated by low voltage, on certain types of equipment. The use of synchronous converters is sometimes not permissible because of inferior voltage regulation of the supply. The a-c. input being electrically connected (through the converter windings) to the d-c. feeders, the a-c. voltage fluctuations are reflected in the d-c. voltage. Excessive fluctuations in a-c. voltage generally result in serious operating difficulties with synchronous converters. Motor-generators afford much more reliable operation under these conditions, although the electrical efficiency is much lower than that of synchronous converters.

Synchronous converters, instead of motor-generators, were recently selected for two mine substations, where conditions for their use were favorable and no power factor correction was required, as the difference in efficiency at average loads gave an annual saving, in the over-all cost of power service for a 2000-ton mine, of $3600. The question of motor-generator sets versus synchronous converters, for mine service, is often decided by factors other then power costs and it is possibly not pertinent to comment at length upon it.

Fuel costs form the major portion of plant operating expenses in all steam-driven plants, hence considerable variations in the cost or quality of coal must of necessity be reflected into rate schedules. In large and medium capacity modern turbo-generator plants the fuel cost is about two-thirds of the total station operating cost, hence, the tendency to higher steam pressures, highest possible vacuum and larger generating units.

It is not difficult, when the average fuel consumption in lb. per delivered kw-hr. is known, to construct an equitable factor for use in a coal cost variant clause, in a rate schedule. Similarly, a correction factor for variations in calorific value of fuel used can easily be worked out. Both provisions are sometimes incorporated in large or long term power contracts and rate schedules. In a recent contract, negotiated by the writer, it was found that the utility was demanding a fuel cost provision which was nearly four times its actual fuel cost increase.

Heretofore, the application of coal cost clauses to rates has been confined to the larger power schedules whose energy costs carried a relatively large portion of fuel expense. A recent departure is noted in the coal clauses filed by the three more important companies in Greater New York, providing for a differential, for all consumers, of 0.05 cents per kw-hr. for each 10 cent change, from $3.00 (average cost in 1916 when present rates were filed) in the cost per ton of coal. It of course, remains to be seen how generally this clause will be filed by other utilities.

The term "fair value", so frequently used in utility valuations for rate determinations, is often difficult to define accurately as a basis. Only that property "used and useful" in the supply of power service is appraised in rate fixing. Rates are often approved or disapproved upon estimates derived principally from operating cost records, as accurate valuations of physical and intangible property require much time and are generally very expensive and the cost must ultimately be borne by the consumers. The subject of valuation and its influence upon power rates is too extensive to form a part of this discussion, but those sufficiently interested can secure a copy of Valuation of Public Utility Properties, by Henry Floy, or Valuation, Depreciation and the Rate-Base, by Grunsky. A comprehensive outline of property accounting is contained in the Classification of Accounts for Electric Companies prescribed by the Public Service Commission of Pennsylvania. A similar classification is used by the Public Utilities Commission of Ohio.

The proper provision in cost accounts and the effect on rate schedules of "depreciation", so extensively discussed in rate problems are barely mentioned. The magnitude of depreciation depends, on the adequacy of prior maintenance and upon customs and individual peculiarities, and it is often an uncertain and somewhat theoretical quantity, but also a factor that should not be ignored or misused. The general subject of rates for electric power service is much too broad to admit of any but brief references to several factors of importance. A copy of Principles of Depreciation, by Salier, will inform you of the distinction between unit, composite and functional depreciation, obsolescence, inadequacy, etc.

It is an interesting fact that only a small part of an enormous public utility debt upon which interest has been defaulted is in electric light and power securities. A recent compilation of approximately $500,000,000, shows that only about $9,100,000, or 1.8 per cent of securities were in bonds of purely electric light and power companies and about $41,278,000 or only 8.25 per cent were in combination railway and electric properties. The fact that during the very de-

cided "seller's market" of the war period, the price of electrical energy has been realtively very low as compared with most any commodity that you may name, is another fact of direct interest to you.

Accurate comparisons of rate schedules with average costs of delivered power will often show that a power company "lives upon and by virtue of its diversity factors."

Induction Motor Nomogram

A Movable Diagram for Reading all Performance Characteristics of any Three-Phase Induction Motor

BY R. G. WARNER
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THE field of the circle diagram, aside from the design standpoint, is the determination of the characteristics of a motor without the necessity of actual loading.

Inasmuch as the full load value of current is quite low on the circle (15 to 20 per cent of its diameter) a large circle is required, of which only a small portion is utilized. Furthermore, a new circle must be drawn for each motor. For these reasons I have constructed a nomogram to depict the performance characteristics of three-phase, 60-cycle motors. This nomogram, Figs. 1 and 2, is based on the simple circle diagram and

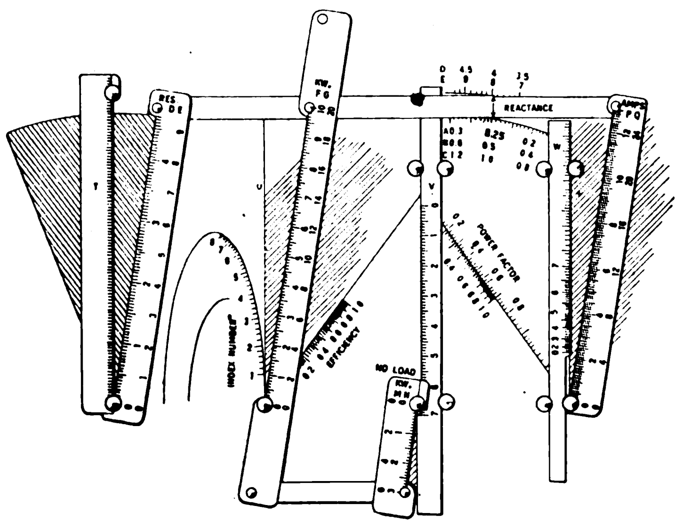

FIG. 1

utilizes the portion for values up to 150 per cent or 200 per cent rated load, depending on the particular motor.

In this nomogram, scales T and U are stationary, scales A to S are pivoted at O and move together and scales V and W slide vertically. The index numbers correspond to points on the circle diagram, any one of which might be chosen to determine values of the characteristics.

REQUIRED MOTOR DATA

The data required to use this nomogram are the same as those required to construct the circle diagram, namely the voltage, current and power for the locked rotor condition and the no-load condition and the primary resistance.

Calculate from the locked rotor values

$$R_e = \frac{W_1 + W_2}{3\,I^2}$$

$$Z_e = \frac{E^2}{3\,I^2}$$

$$X_e = \sqrt{Z_e^2 - R_e^2}$$

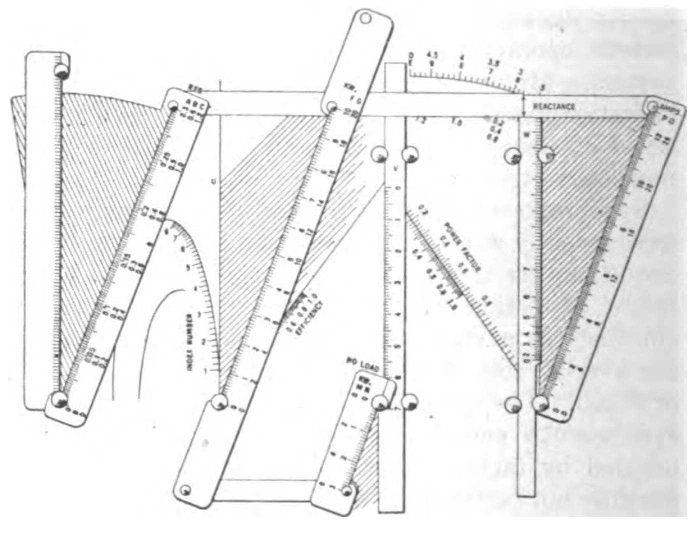

FIG. 2

W_1 and W_2 are the two wattmeter readings as commonly connected for reading the power, I is the current per terminal and E the voltage between terminals.

From the no-load readings, calculate

$$\text{kw.} = \frac{W_{01} + W_{02}}{1000}$$

$$I_0 \sin\theta = \sqrt{I_0^2 - \frac{(W_{01} + W_{02})}{3\,E^2}}$$

The average primary resistance per phase, R_1.

DIRECTIONS

For any particular motor arrange to use for the various quantities the scales as given in the following

table. For example, for a 10-h. p., 220-volt motor, use scales C, G, M and R.

TABLE I

H. P.	Volt	X_e	R_e	Kw.	No-Load Kw.	Amperes
5	110	B	B	F	N	R
5	220	Cx2	Cx2	F	N	Q
5	440	E	E	F	N	P
10	110	A	A	G	M	S
10	220	C	C	G	M	R
10	440	D	D	G	M	Q
20	220	B	B	H	L	S
20	440	Cx2	Cx2	H	L	R
40	440	C	C	I	K	S

For motors of other ratings use scales for the nearest size motor of the same voltage.

Scales D & E are on rear of scales A B C

Scales H & I are on rear of scales F G

Scales K & L are on rear of scales M N

Scales R & S are on rear of scales P Q

1. Set reactance arrow for calculated value of reactance. This will set scales A to S.

2. Set scale V so that 7 on scale V indicates along guide ines to no-load kw.

3. Set scale W so that O indicates along guide lines to I_0 Sin θ on "Amperes."

4. To find torque, from value on T corresponding to primary resistance, project through an index number to U and read value of torque in synchronous watts on kw. scale. To convert this value to pound-feet multiply kw. $\times K/n$ where K is a constant $= 7040$ and n is the synchronous speed of the motor.

5. To find the corresponding output, project from value of R_e on T through the same index number as in 4 to U and read output on kw. scale.

6. To find efficiency, connect point on U (found in 5) to corresponding index number on V and read on efficiency scale.

7. To find power factor, connect index number on V to index number on W and read power factor on black (upper) scale.

8. To find current, project index number on V through power factor on red (lower) scale and read amperes indicated by W along guide lines to current scale.

9. To find speed, calculate

$$\text{speed} = \frac{K\,W}{T}\,n$$

where $K\,W$ is output found in 5, T is torque in synchronous watts found in 4, and n is the synchronous speed.

As many sets of values as desired may be obtained by using various values of the index number.[1]

10. To find the maximum values of torque of a motor, project from resistance value equal to the primary resistance on scale T by means of a tangent to the index number curve to scale U. The maximum torque is read on F, G, H or I in synchronous watts corresponding to point on scale U.

Should this value be beyond the range of the scale a smaller curve is shown directly under the main index number curve. By projecting tangent to this curve the value of torque as read should be doubled.

11. To find the starting torque of the motor, project from value of resistance on scale T corresponding to total resistance to $K\,W$ equal to 0. Using point where this line intersects the index number curve, project from value of resistance equal to primary resistance to scale U and read starting torque in synchronous watts on scales F, G, H or I. As before should this value of synchronous watts be beyond the readable scale the smaller index number curve may be used as stated above.

12. To find the maximum output, project from value of resistance corresponding to total resistance of motor a line tangent to the index number curve to scale U and read corresponding value of output on scales F, G, H or I. Should the value of maximum output be beyond the readable scale the smaller index number curve may be used as above.

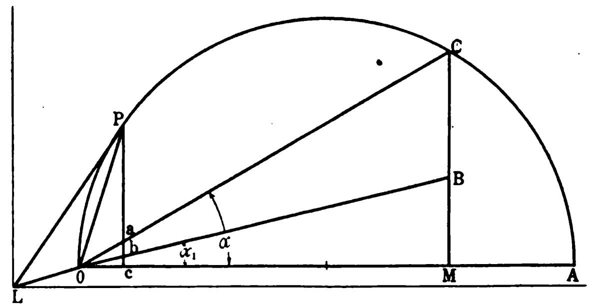

FIG. 3

Basic Construction

The nomogram framework is constructed for a hypothetical induction motor of circle diameter equal to 200 amperes, total reactance equal to 1 and voltage per phase equal to 200. From this the watt scale equals $3\,E_p$ times the I scale, or 1 ampere in phase with the voltage is the equivalent of 600 watts.

The pivoted scales enable one to change from one motor to another when it is desired, and will not be discussed until later. For the present, consider these in the vertical position.

The T scale is actually the ratio of resistance to reactance or the slope of line $O\,C$ in Fig. 3. This ratio is $\tan \angle\, C\,O\,M$, or $\tan\,\alpha$, and $\tan \angle\, B\,O\,M = \tan\,\alpha_1$. This is, however, marked in terms of resistance.

The index number is the actual in-phase component of current of this hypothetical motor divided by 10, or $P\,c$ in Fig. 3.

Scale U is the component of current representing output of this hypothetical motor, or $P\,a$ in Fig. 3.

1. It will be noted that the index number may be chosen for any desired value of output by connecting from value of total resistance to kw. and reading index number.

Scale V is the actual in-phase component of current of this hypothetical motor divided by 10, or $P\,c$ in Fig. 3. When this scale is moved down, a portion is added representing the no-load losses, an amount equal to the in-phase component of $L\,O$.

Scale W is the reactive component of current $O\,c$, but since it has a definite relation to $P\,c$ is labelled in terms of $P\,c$, the index number. When scale W is moved upward a portion is added representing the reactive component of $L\,O$.

When scale W is used with the red (lower) scale of power factor it represents the current $L\,P$.

Relation Between "T" and "U"

The equation of the hypothetical motor in question (assuming the origin at O) has its current locus given by

$$x^2 + y^2 - 200\,x = 0$$

or $y = \sqrt{200\,x - x^2}$

Output $= E\sqrt{200\,x - x^2} - d\,x\,R_e$

where $d = E/x_e =$ diameter

Dividing by E to obtain component of current $P\,a$ (Fig. 3.)

$$P\,a = \sqrt{200\,x - x^2} - x\,R_e/X_e$$
$$= \sqrt{200\,x - x^2} - x\tan\alpha$$

Where

$$\tan\alpha = R_e/X_e$$
$$= \tan\angle\,C\,O\,M$$

This makes an equation of three variables which may be written in a determinant

$$\begin{vmatrix} -1 & a & 1 \\ 1 & b & 1 \\ 1-c & d & 1+c \end{vmatrix} = 0$$

Where $a = \tan\alpha$

$b = P\,a$

$c = x$

$d = \sqrt{200\,x - x^2}$

This may be represented in cartesian coordinates by parametric equations of three curves, corresponding points being given by an intersecting straight line.

(1) $x = -1$ $\quad y = a$

(2) $x = 1$ $\quad y = b$

(3) $x = \dfrac{1-c}{1+c}$ $\quad y = \dfrac{d}{1+c}$

For the results we wish in a motor

a should vary from 0 to 0.7

b should vary from 0 to 70

c should vary from 0 to 30

d should vary from 0 to 70

If plotted to the same scale a would be very small, so we change the scale factors multiplying by factors u_1 and u_2.

(1) $x = -1$ $\quad y = u_1\,a$

(2) $x = 1$ $\quad y = u_2\,b$

(3) $x = \dfrac{u_1 - u_2\,c}{u_1 + u_2\,c}$ $\quad y = \dfrac{u_1\,u_2\,d}{u_1 + u_2\,c}$

Let $u_1 = 100\,u_2$

Curves (1) and (2) will be straight lines.

Curve (3) in parametric form is

$$x = \frac{100 - c}{100 + c} \quad y = \frac{100\,u_2\,d}{100 + c}$$

Curve (1) is represented by scale T and is calibrated in terms of resistance since the reactance is constant and in this case equal to 1.

Curve (2) is represented by scale U.

Curve (3) is the curve marked "Index Number."

The torque, $P\,b$, may be shown by the same curves by using for values of a, $\tan\alpha_1$, since $Pb = \sqrt{200\,x - x^2} - x\tan\alpha_1$.

Relation between U and V

U represents $P\,a$, the output component of current, V (in position) represents $P\,c$ + no-load power component of current, the total power input component of current.

$$\text{Efficiency} = \frac{P\,a}{P\,c + \text{no-load power current}}$$

This again may be expressed in determinants and by parametric equations of three straight lines, of which $P\,a$ (U) and $P\,c$ (V) are regular. The efficiency scale is plotted for distance from a point 0, where efficiency is marked 1, to -1 where efficiency is marked 0 according to the function

$$\text{Distance} = \frac{\text{efficiency} - 1}{\text{efficiency} + 1}$$

Relation between V and W

Scale V (in position) represents the power component of current $P\,c$ + no-load power component of current, and W (in position) represents the reactive component of current $O\,c$ + reactive component of $L\,O$.

The (upper) scale marked power factor is plotted for distances from $+1$ where power factor $= 0$ to -1 where power factor $= 100$ per cent according to the function

$$\text{Distance} = \frac{\tan\theta - 1}{\tan\theta + 1}$$

Instead of being marked in terms of $\tan\theta$, the scale is marked in terms of the corresponding power factor.

The (lower) scale marked power factor is plotted for distances from -1 where power factor $= 0$ to 0 where power factor $= 100$ per cent according to the function

$$\text{Distance} = \frac{\cos\theta - 1}{\cos\theta + 1}$$

In this case

$$\text{Cos}\,\theta = \frac{P\,c}{O\,P} = \frac{V}{W}$$

or when V and W are moved to add the components of $L\,O$

$$\text{Cos}\,\theta = \frac{P\,a + \text{power component of } L\,O}{L\,P}$$

CHANGE OF X_e

When we change from one motor to another of the same voltage the effective reactance will change. Now let us consider that our hypothetical motor had a maximum ordinate of 100 per cent rather than 100 amperes, and that our index number represents per cent instead of amperes. Then point 3 will represent 30 per cent of the maximum ordinate.

Choose a new motor for the same voltage which would have a total reactance of say 0.5. This would represent a motor of approximately twice the capacity of the first. Our new diameter $O\,A$, Fig. 3, would represent $\frac{200}{0.5}$ or 400 amperes. Now point 3 representing 30 per cent of the maximum ordinate is equivalent to 60 amperes. Since the kw. per ampere is dependent only on the voltage, the scale readings of watts and

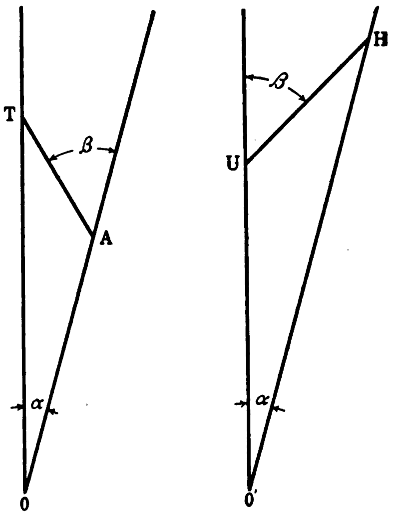

FIG. 4

amperes should be increased proportionally. This is done by moving scales H to S inclusive by the same angle, and by the law of similar triangles the ratio is the same (see Fig. 1). These are moved, so that referring to Fig. 4

$$\frac{O'\,U}{O'\,H} = \frac{X_e}{1} \text{ where the basic } X_e = 1$$

The T scale is a ratio of resistance to reactance, hence as the reactance is reduced the resistance must be reduced proportionally to have the same ratio at a given point. This is done by changing the angle of the guide lines with the scale of resistance. Referring to Fig. 4, T and U are stationary and A and H move together so that angle $T\,O\,A$ is always equal to angle $U\,O'\,H$. Angle $O\,A\,T$ is constant and equal to angle $O'\,U\,H$. Hence by similar triangles

$$\frac{O\,A}{O\,T} = \frac{O'\,U}{O'\,H}$$

$$\text{but } \frac{O'\,U}{O'\,H} = \frac{X_e}{1}$$

As T represents actually the ratio of resistance to reactance, if the reactance is decreased then the resistance should be decreased proportionally, which is done, since

$$\frac{O\,A}{O\,T} = \frac{X_e}{1}$$

CHANGE OF VOLTAGE

When the voltage is changed and the reactance kept constant, the diameter, $\frac{E}{X_e}$ is changed proportionally. Suppose the voltage to be doubled, then the diameter is doubled and the watts per ampere are doubled.

Again, point 3, or 30 per cent of the maximum ordinate, will represent 60 amperes, and as the watts per ampere are doubled this will represent four times as many watts. As the commercial voltages change in very definite steps, usually doubling, this change of voltage is taken care of in general by changing scales by multiples of 2.

As the resistance scale is actually a ratio to reactance this does not change due to voltage alone.

CHANGE OF RATING—VOLTAGE CONSTANT

Changing from one set of scales to another was described under changes of voltage. This may equally well be required under change of reactance. For example, two motors of the same voltage but of considerably different reactance will have considerable difference in rating, *i. e.* a 5-h. p., 220-volt motor would have approximately twice the reactance of a 10-h. p., 220-volt motor. It is better, then, in changing from a 5 to a 10-h. p. motor, to change scales. Change the reactance scale to one of one-half the value. Inasmuch as the current scale represents per cent of maximum ordinate and the maximum ordinate is doubled, the current scale should be doubled. As the watts per ampere for a given voltage are constant the watt scale must be doubled. As the resistance is actually a ratio to the reactance it must be changed to a scale corresponding to the reactance.

CHANGE OF VOLTAGE RATING

If two motors of the same horse power rating are considered, but one is rated at one-half the voltage of the second, it is again necessary to change the scales. For a given rating, if the voltage is doubled the current is halved, consequently the diameter of the circle, $\frac{E}{X_e}$, is one-fourth. We then change to a reactance scale of one-fourth value. As the maximum ordinate is one-half, the current scale should be one-half. As the watts per ampere are doubled, the watt scale should be the same. The resistance scale as before should be changed to correspond to the reactance scale.

Present Scales

Values for the present sets of scales are chosen to give the expected values for motors from 5 to 25 h. p. The kw. scale is the basic scale. Referring to the scale D, 7 kw. represents 70 per cent of the maximum ordinate of the circle. For 110 volts then the maximum ordinate in amperes would be 52.5 per phase. The reactance per phase would be

$$X_e = \frac{E_p}{52.5 \times 2} = 0.605$$

This in turn determines the resistance scale. Other scales are actually multiples of this set.

New Scales

From the previous discussion I believe it is possible to construct new scales as in the following. To use the nomogram for an 800-h. p., 2200-volt, three-phase, 60-cycle, 350-rev. per min. induction motor: The short-circuit characteristic gives the following data:

$$R_e = \frac{655.000}{3 \times 900^2} = 0.269$$

$$R_1 = 0.1893$$

$$X_e = \sqrt{\left(\frac{1270}{900}\right)^2 - 0.269^2} = 1.358$$

Watts per ampere

$$2200 \times \sqrt{3} = 3.81 \text{ kw.}$$

Max. ordinate

$$\frac{E}{2\,X_e} = \frac{1270}{2.770} = 459 \text{ amperes}$$

$$459 \times 3.81 = 1750 \text{ kw.}$$

0.3 Max. ordinate, $459 \times 0.3 =$ 138 amperes
$1750 \times 0.3 =$ 525 amperes

It will be noticed that $X_e = 1.385$ may be determined on scale C times 2 or scale D divided by 2. Referring to Table of Scales, page 809, scale C times 2 is used with F, N, Q, for a 5-h. p., 220-volt motor. It will be noted that this is applicable to the motor in question if the scale of amperes is multiplied by 10 and the kw. scale by 100 to account for the different voltages.

Example

By running the motor light at normal voltage it is found:

$I_0 = 66.4$
$W_0 = 21.6$ kw.

and power factor

$= 8.56$ per cent

Proceed as follows: (See Fig. 2)

Set reactance to indicate 1.385 on scale $C \times 2$ or scale D divided by 2

Set scale V to indicate 21.6 kw. on scale $N \times 100$

Set scale W to indicate 66 amperes on scale $Q \times 10$

Read as follows for full load:

From Res. = 0.269 on scale $C \times 2$ as indicated on T read to 597 kw. as indicated by scale F on U and read index number 3.65.

From 597 kw. to index number 3.65 on scale V and read efficiency 0.93.

From index number 3.65 on scale V to index number 3.65 on scale W and read power factor 0.88.

From index number 3.65 on scale V through power factor (lower scale) equal to 0.88 read current per terminal on scale $Q \times 100$ (as indicated on W) 194 amperes. For torque, from Res. = 0.189 as indicated by scale $C \times 2$ on T through index number 3.65 read on scale $F \times 100$ (as indicated on U) 602 synchronous kw.

$$= \text{Slip} = \frac{602 - 595}{602}$$

$$= \frac{7}{602} = 1 + \text{per cent}$$

Maximum output is obtained by projecting from Res. = 0.269 on scale T tangent to smaller index number curve and reading on scale $F \times 200$, 1300 kw. (as indicated on U). Similarly maximum torque is read by projecting from resistance = 0.189 tangent to index curve and reading 1480 kw. synchronous torque on scale $F \times 200$ as indicated on U.

Starting torque is found as 180 kw. synchronous torque by projecting from resistance = 0.269 to zero kw. and through point thus found on index curve projecting from resistance equal to 0.189 to scale U reading on scale F.

The following is descriptive of the methods used in constructing various portions of the nomogram.

Index Number Scale

Preliminary sketches of the curve on which the index number scale appears, indicated a curve which approximated a circle with certain scale factors. As a circle is more easily drawn than most curves the equation of the circle was obtained as follows.

In parametric form (see p. 810):

$$x = \frac{u_1 - u_2\,c}{u_1 + u_2\,c} \tag{1}$$

$$y = \frac{u_1\,u_2\,d}{u_1 + u_2\,c} \tag{2}$$

Eliminating c and d

$$\begin{aligned} c &= x_1\,d \\ &= \sqrt{200\,x_1 - x_1^2} \\ &= \sqrt{200\,c - c^2} \end{aligned} \tag{3}$$

From (1)

$$\begin{aligned} x\,u_1 + x\,u_2\,c &= u_1 - u_2\,c \\ c\,u_2\,(x+1) &= u_1\,(1-x) \\ c &= \frac{u_1}{u_2}\,\frac{1-x}{1+x} \end{aligned}$$

Substituting in (3)

$$d = \sqrt{\frac{200\,u_1\,(1-x)}{u_2\,(1+x)} + \frac{u_1^2\,(1-x)^2}{u_2^2\,(1+x)^2}}$$

$$= \frac{1}{u_2\,(1+x)}\sqrt{200\,u_1\,u_2\,(1-x^2) - u_1^2\,(1-x)^2}$$

From (2)

$$y\, u_1 + y\, u_2\, c = u_1\, u_2\, d$$

$$y\, u_1 (1 + x) + y\, u_1 (1 - x) = \mu\, 1 \sqrt{200\, u_1\, u_2 (1 - x^2) - u_1^2 (1 - x)^2}$$

$$(2\, y)^2 = 200\, u_1\, u_2 (1 - x^2) - u_1^2 (1 - x)^2$$

$$4\, y^2 = -\,200\, u_1\, u_2\, x^2 - u_1^2\, x^2 + 2\, u_1^2\, x + 200\, u_1\, u_2 - u_1^2$$

$$x^2 (u_1^2 + 200\, u_1\, u_2) + 4\, y^2 - 2\, u_1^2\, x - 200\, u_1\, u_2 + u_1^2 = 0$$

$$x^2 - \frac{2\, u_1^2}{u_1^2 + 200\, u_1\, u_2} + \frac{4\, y^2}{u_1^2 + 200\, u_1\, u_2} + \frac{u_1^2 - 200\, u_1\, u_2}{u_1^2 + 200\, u_1\, u_2} = 0$$

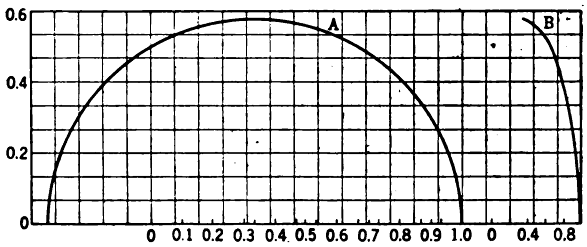

Fig. 5—Index Scale Construction

This is the equation of a circle if scales are chosen such that

$$u_1^2 + 200\, u_1\, u_2 = 4$$

In this case the center is at

$$y = 0$$

$$x = \frac{u_1}{u_1 + 200\, u_2}$$

$$\text{Radius} = -\,\frac{u_1 - 200\, u_2}{u_1 + 200\, u_2} + \frac{u_1}{(u_1 + 200\, u_2)}$$

$$\text{Radius} = \frac{200\, u_2}{u_1 + 200\, u_2}$$

$$\text{When } u_1 = 100\, u_2$$

$$\text{Center becomes} = \frac{u_1}{u_1 + 2\, u_1} = \frac{1}{3}$$

$$\text{Radius} = \frac{2\, u_1}{u_1 + 2\, u_1} = \frac{2}{3}$$

Ratio of x to y scale

$$u_1^2 + 2\, u_1^2 = 4$$

$$3\, u_1^2 = 4$$

$$u_1 = \frac{2}{\sqrt{3}} = 1.154$$

$$\frac{1}{u} = 0.86$$

This circle was drawn to scale so that the ordinate was correct for the nomogram, curve A, Fig. 5. The abscissa was then reduced to correct scale for nomogram and the curve B drawn and was then readily transferred to the nomogram.

Since, with resistance zero, the index number equals the ordinate, the index number scale was divided by connecting point res. = 0 to various points on watt scale and marking the index scale accordingly.

Reactance Scale

Referring to Fig. 6B,

$$O\, b = \frac{O\, c}{\text{Cos}\,(\alpha + 90 - B)}$$

$$O\, a = \frac{O\, c}{\text{Cos}\,(90 - B)}$$

$$\frac{O\, b}{O\, a} = \frac{\text{Cos}\,(90 - B) + X_a}{\text{Cos}\,(\alpha + 90 - B)\, X_b}$$

Where X_a is the reactance corresponding to $O\,a$
and X_b is the reactance corresponding to $O\,b$
B is 45 degrees

$$\frac{O\, b}{O\, a} = \frac{1}{\text{Cos}\,(\alpha + 45)} = \frac{1}{\text{Cos}\,\alpha - \text{Sin}\,\alpha} = \frac{X_a}{X_b}$$

$$\text{or } X_b = X_a\,(\text{Cos}\,\alpha - \text{Sin}\,\alpha)$$

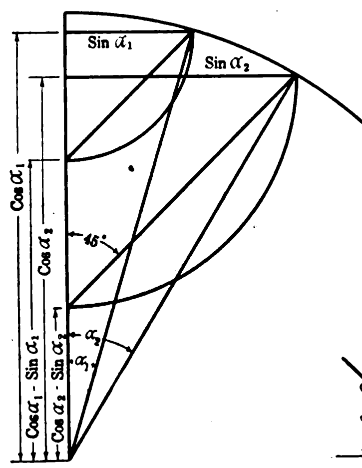

Fig. 6A

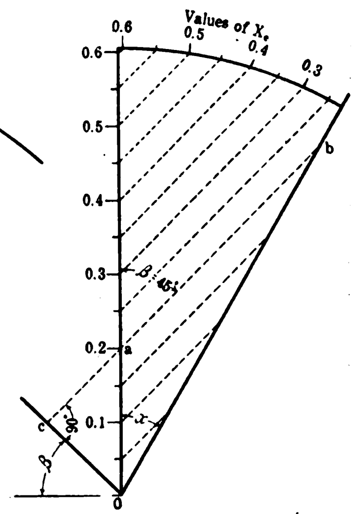

Fig. 6B

Cos α – Sin α may be graphically constructed by means of a compass as shown in Fig. 6A. Another method of obtaining the same result is by means of a 45-deg. line from the extremity of the radius which is rotated through some angle α, Fig. 6A. This leads to the construction shown in Fig. 6B. A temporary vertical scale of reactance was used and its values were projected by 45-deg. guide lines to determine the permanent scale of reactance. It is marked the same as the value of the temporary scale, which is

$$X_a\,(\text{Cos}\,\alpha - \text{Sin}\,\alpha)$$

Other Scales

All of the moving scales were marked by a dividing engine. The desired distances between divisions were calculated and tabulated in millimeters in advance.

The fixed scales of efficiency and power factor were divided by connecting two points of the desired ratio and marking accordingly. In general 10 or 5 was chosen for the denominator of the ratio.

A large amount of the basic nomographical methods used has been obtained from material which will be published in Professor H. L. Seward's "Construction of Permanent Diagrams for Engineering Formulae."

CORRESPONDENCE

DEVELOPMENT OF THE CIRCLE DIAGRAM

To the Editor:

The writer's article published in the May 1920 JOURNAL, page 458, entitled *Theory of Speed and Power Factor Control of Large Induction Motors by Neutralized Polyphase Alternating Current Commutator Machines* contained the following reference note:

For the development of the circle diagram, particular mention should be made of the works of Behrend, Blondel and Arnold-la Cour. Meyer-Delius has also written concerning what the writer has termed single-range regulation.

This note gave insufficient detail, resulting in the impression that originality was claimed for more of the ideas than were actually new. The writer therefore wishes to state that diagrams like Fig. 6, Fig. 9 and Fig. 11 were developed by Dr. H. Meyer-Delius and published in *Electrotechnische Zeitschrift*, May 1913, page 496, the article referred to in the above reference note.

The writer has later been informed by Dr. Meyer-Delius that the latter had also prepared, but not published, a diagram like Fig. 13.

The works of Alexander Heyland should also be mentioned for the development of the circle diagram.

The writer regrets any injustice done by the brevity of the former reference note and hopes the above will correct any existing wrong impression.

JOHN I. HULL
General Electric Co.

EDDY CURRENT LOSSES—A CORRECTION

To the Editor:

In attempting to apply the formulas of my article entitled *Tooth Frequency Losses in Rotating Machines*, which appeared in the A. I. E. E. JOURNAL, September 1921, to actual machines, it was noted that formula 4, page 755, for the tooth pulsation eddy current loss gave values much too low. The original calculations were then checked and a numerical error was found which altogether alters the conclusions in regard to the magnitude of the eddy current losses. The constant in this formula should be 1.3×10^{-7} instead of 1.96×10^{-9}. This makes the calculated eddy loss in the example, page 756, equal to 25.2 watts instead of 0.38. Therefore under the assumed conditions the eddy current loss due to the tooth pulsations is approximately equal to the total fundamental losses plus the tooth-pulsation hysteresis loss. In other words, for 17-mil sheet the tooth pulsation eddy current losses are as we have found by actual tests a large percentage of the total pulsation losses instead of being negligible as previously stated. The writer greatly regrets this error and trusts that you will call it to the attention of your readers in order that those who attempt to use this formula will not be led astray.

THOMAS SPOONER
Westinghouse Electric & Mfg. Co.

TELEGRAPH AND TELEPHONE NOTES

The wide extension of amateur and experimental radio installations throughout the country, together with the probable widespread use of radio telephone stations for Broadcast service, has prompted the compilers of the National Electric Code to incorporate in that publication revised rules to meet the changing conditions. The Standardization Committee of the Institute of Radio Engineers, New York, now has in hand the framing of a set of regulations to be recommended for inclusion in the next edition of the Code.

The telegraph and telephone section, American Railroad Association, has up with the Secretary of Commerce, Washington, the matter of securing modification of the regulation that telegraphers operating radio telegraph transmitting stations must use the Continental alphabet. In the near future several railroads expect to employ radio in the handling of message traffic, where the system can be used to advantage, and it is desired that telegraphers already in the service of the railroads and who use only the American Morse code be permitted to operate the stations without having to learn the Continental alphabet. The American Morse code is used on all land line systems in the United States and Canada. J. D. Jones, superintendent of telegraph, Pennsylvania Railroad, Philadelphia, is chairman of the A. R. A., committee.

Short-distance printing telegraph systems are now successfully applied in a number of industrial plants to meet modern requirements of internal communication. Systems now available are simple, economical and reliable.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. NOVEMBER MEETING
JOINT SESSION WITH THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

The 372d meeting of the Institute will be held in the Engineering Societies Building on Thursday, November 17, 1921. The meeting will consist of an afternoon and an evening session.

The afternoon session will be a joint session with the Society of Naval Architects and Marine Engineers, forming a part of the annual meeting of that society. Two papers will be presented at this session as follows:

Electric Auxiliaries, by E. D. Dickinson, Marine department of the General Electric Co.

Electric Propulsion, by W. E. Thau, Commerical Engineer of the Westinghouse Electric and Mfg. Co.

The paper by Mr. Dickinson is printed elsewhere in this issue of the JOURNAL.

The evening session will be devoted to a lecture on *World Communication*, by Alfred N. Goldsmith, Professor of Electrical Engineering, City College of New York.

NEW YORK SECTION MEETING
October 19, 1921

The first N. Y. Section meeting for the new administrative year will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York on Wednesday evening, October 19th. This will be a joint meeting with the New York Sections of the A. S. M. E., the A. S. C. E., and the A. I. M. E. The subject to be discussed will be "Engineering Financing" and while it is impossible at the present time to announce the speaker's names, every effort is being made to obtain men of particular prominence in this field. A detailed announcement will be mailed to the membership as soon as possible.

The complete schedule of N. Y. Section meetings for the year follows.

1. Engineering Financing, October 19, 1921.
2. The Great Lakes, St. Lawrence Canal, November 14th, 1921.
3. Central Station Operating, December 14th, 1921.
4. Industrial Power Requirements, January 27th, 1922.
5. The Port of New York, March 15, 1922.
6. (Subject to be announced later), April 19, 1922.

PHILADELPHIA SECTION MEETING
OCTOBER 10, 1921

The first scheduled meeting this season of the Philadelphia Section of the A. I. E. E. will be held on October 10th at the Engineers Club, 1317 Spruce Street, Philadelphia. The speaker will be Mr. Frank B. Gilbreth and the subject, "One Best Way to do Work."

The Philadelphia Section cordially invites the attendance of members of adjoining Sections.

ENGINEERING FOUNDATION

A regular meeting of Engineering Foundation was held September 8 at which several research projects were discussed as follows:

Fatigue of Metals. Correspondence with the University of Illinois, Engineering Experiment Station, was submitted. It was stated that the complete report on the research, in manuscript form, had been sent to the office of the Division of Engineering, National Research Council, and would within a few days, be delivered to Engineering Foundation office. On suggestion of Chairman Rand, it was voted that the manuscript of the report on Fatigue of Metals research, drafted by the Engineering Experiment Station, University of Illinois, and approved by the Advisory Committee of National Research Council be referred to Dr. Goss for examination and advice as to approval on behalf of Engineering Foundation.

Steam Tables. Communication dated July 30 from American Society of Mechanical Engineers, requested assistance of Engineering Foundation in a "research for determining constants for the upper limits of steam tables." Chairman Arthur M. Greene, Jr., of the Society's research committee, gave information concerning the need, plans and anticipated support for the proposed research and suggested a modest contribution to be spread over three years. It was voted that Engineering Foundation contribute toward expenses for research for determining constants for the upper limits of steam tables, under the auspices of the American Society of Mechanical Engineers, and that Dr. D. S. Jacobus represent Engineering Foundation in the conduct of the Steam Tables research.

Graphitic Corrosion of Cast Iron. Mr. J. Vipond Davies described deterioration of cast iron exposed to salt or brackish water, or buried in soils impregnated with certain salts or acids, by which the character of the castings in part or whole is changed from that of metallic iron to that of graphite, which can be readily cut with a knife. He suggested the name "Graphitic Corrosion" for this form of deterioration, and stated that it had been known for many years, was not understood, and affected water and gas pipes, pumps and condensers of steam plants parts of sea-going vessels, and other objects. It was constantly causing loss and danger, and was doubtless the cause of much damage attributed to electrolysis by stray currents. He had been studying the problem for twelve years, or more, in the interest of clients, with the aid of numerous experts, but with small increase of knowledge. Because of the importance to many industries and engineers, he suggested a comprehensive

research by Engineering Foundation and offered to cooperate by making available results of his own investigations. Mr. Moultrop and the Secretary told also of their experiences along these lines. It was referred to Executive Committee for study and recommendation.

EMPLOYMENT SERVICE

The employment service which the Institute has maintained for many years and which since January 1921, has been conducted under the auspices of the Federated American Engineering Societies has been making great efforts during the present year to aid in the solution of the employment problem in the engineering field.

With 1500 unemployed engineers registered at the Bureau's headquarters, 33 West 39th Street, New York, men of many degrees of experience, from the most recent graduate to the high salaried executive, it was early recognized by the Management Board that, in addition to the regular systematic routine of operation, the Bureau must adopt special measures to cope with the situation and with this end in view an additional appropriation was asked and obtained from the Federation. Members of the Institute are earnestly requested to advise the Bureau of openings within their own organization or of outside opportunities of which they may know. Particular emphasis is laid upon the many advantages to the employer of dealing with the Federation Bureau, the large number of men with whom the Bureau is in touch, the comprehensive classification of educational and professional records, available, and the fact that the services of the Bureau are free.

A Volunteer Committee, composed of engineers registered with the Bureau, was organized early in the summer and undertook at their own expense the task of having the attention of every employer of engineers in New York City called to the available facilities of the Engineering Bureau, through one or more personal visits. This work was so systematically laid out that there was no duplication of effort, no possibilities overlooked and the results were tabulated for present and future use. Up to August 12th, the calls made amounted to 1623 and the interviews granted 1009, resulting in 36 opportunities for employment and 59 prospective positions. This work has been in progress in New York since before June 1st and is now nearing an end. It is hoped to have a similar canvas carried on in other large cities.

Through the campaign, as outlined, it is expected that the scope of the Bureau will be greatly increased and with that increased scope will come its ability to be of even greater service to members of the Engineering Societies in the future than it has been in the past.

PERSONAL MENTION

W. M. Brown formerly Electrician with the Martinez Electric Co., is now Electrician with the Union Pacific Coal Co.

T. H. McWhirk who was with the General Electric Co. at Atlanta, is now Chief Electrician aboard the U. S. S. *Maryland*.

William G. Dow formerly of the Industrial Sales Department, Westinghouse Electric & Manufacturing Co., is now Testing Engineer, Commonwealth Edison Co., Chicago, Ill.

W. D. Cannon formerly Research Graduate Assistant, University of Illinois, is now Engineering Assistant, Western Union Telegraph Co., 195 Broadway, New York.

F. P. Townsend has severed his connection as electrical engineer, Submarine Boat Corporation, and is now connected with the Kindred Appliances Co., 39 Cortlandt Street, New York.

E. E. Perkins, Jr., formerly of the Carroll Electric Co., has been appointed assistant instructor in electrical engineering at the University of Illinois, Urbana, Ill.

F. S. Bird formerly General Superintendent, Texas Construction Co., is now with the Oil Belt Power Co. at Eastland, Texas.

Cecil L. Eaton who was Assistant Superintendent, Joseph Meyer, Inc., is now Salesman with the Shiff Auto Supply Co., Box 547, Orlando, Fla.

G. B. Burnham formerly Manager, Burnham Chemical Co., is now Technical Director of the company, with offices at 1016 Hobart Building, San Francisco, Cal.

H. L. Burgess has left the New York office of the American Telephone and Telegraph Co., and is now with the Bell Telephone Co. of Pennsylvania, office 1631 Arch Street, Philadelphia, Pa.

Howard W. Mott has left the Western Electric Co.nd is a now in charge of instruction in electrical engineering at Stuyvesant High School, 345 East 15th Street, New York.

J. E. Cannell formerly Electrical Engineer with Reeds & Thorpe, is now with J. J. Cannell, Electrical Contractor, 20 Chelsea Street, Everett, Mass.

Walter J. Berry has left his position of Operating Engineer for the Hotel Bossert and is now a Salesman with the Superheater & Engineering Co., Room 1816 Woolworth Building, New York.

Earl M. Newlin formerly Assistant Engineer, Superpower Survey, is now connected with Goodwin, Newlin & Co., 133 South 12th Street, Philadelphia, Pa.

J. H. McClure formerly Vice-President, The Ohio Electric Railway Co., is now with the Indiana, Columbus & Eastern Traction Co., Interurban Building, Springfield, Ohio.

A. D. Hecker who was electrical foreman with the American International Shipbuilding Corporation, is now electrician with the Arrow Electric Co., Philadelphia, Pa.

John E. Breese formerly with the Western States Gas & Electric Co., is now draftsman with the Solar Refining Co. Lima, Ohio.

Carl J. Koch formerly Instruction Supervisor, Extension Division, School of Engineering of Milwaukee, is now Switchboard Engineer with the Western Electric Co. of Chicago.

Albert E. Pierce previously Secretary of Blodgett, Hart & Co., is now Vice-President, Harvey Fisk & Sons, 105 South La Salle Street, Chicago, Ill.

R. H. Spring previously Assistant to the Field Electrical Engineer, American Railways Co., is now Manager, Cape May Light & Power Co., Cape May City, N. J.

Lloyd P. Joubert formerly Draftsman with the Todd Dry Dock & Construction Corporation, is now Electrical Engineer, C ty of Takoma Lighting Department, City Hall, Takoma, Wash.

Richard H. Olson a former partner in the firm of Pearson & Olson, is now Sales Engineer with the Electrical Machinery Manufacturing Co., Minneapolis, Minn.

T. B. Pierce formerly President, Kentucky West Virginia Engineering & Electric Co., is now President and General Manager of the Central Electric Co., Huntington, W. Va.

Geo. F. Whitworth formerly Assistant Engineer with the Pacific Gas & Electric Co. is now with the University of California, Berkeley, Cal.

Chas. C. Snyder formerly Distributor, Westinghouse Batteries, is now Manager, Los Angeles Branch of the Coast Equipment Co., Los Angeles, Cal.

A. W. Lynch formerly Superintendent, Water and Light Department of Forest City, N. C., is now Sales Engineer, Piedmont Electric Co., Ashville, N. C.

J. C. Lawler previously Purchasing Department, Great Western Sugar Co. of Denver, is now Manager of the "J-E" Battery Co. of Southern California, Los Angeles, Cal.

W. J. Timmins formerly Assistant Chief of Research Laboratory, Edison Storage Battery Co., is now Construction Engineer with Pewick Bros., Des Moines, Iowa.

R. W. Robinson formerly Chief Operator, Nevada-California Power Co. at Goldfield, is now Construction Engineer with Thomas H. Ince Studios, Culver City, Cal.

John H. McDonnell is now a partner in the firm of Benneche & McDonnell, Electrical Engineers and Contractors, Marion, Ohio.

T. Miwa has opened an office as Consulting Engineer, 1909 Bush Street, San Francisco, Cal. Mr. Miwa was formerly Superintendent of the California Vegetable Packing Co., Ltd., of Los Angeles.

Frank P. Boone formerly Electrical Engineer with the United States Food Products Corporation, is now Superintendent, Meter Department, Southern Illinois Light & Power Co., 902 Central National Bank Building, St. Louis, Mo.

Alex. J. MacAllister formerly Assistant Mechanical Engineer, American Smelting & Refining Co., is now Student Engineer with the Southern California Telephone Co., 716 Olive Street, Los Angeles, Cal.

R. H. Wheeler has left his position as Assistant Construction Manager with Dwight P. Robinson & Co., Inc., and is now General Manager, Western New York & Pennsylvania Traction Co., 142 N. Union Street, Olean, N. Y.

Charles D. Kunkel has accepted position of Power Apparatus Specialist with the Western Electric Co., Los Angeles, Cal. He was formerly Sales Engineer with the Westinghouse Electric & Manufacturing Co. at San Diego.

Marshall J. Maxfield formerly instructor in Electrical Engineering at Pennsylvania State College, has accepted the position of Director of Laboratory Instruction, Department of Industrial Engineering, Pratt Institute, Brooklyn, N. Y.

Arsene Rivero formerly in the Transformer Drafting Department, Westinghouse Electric & Manufacturing Co., is now in the Engineering Department of the New York Edison Co., at Irving Place.

C. T. Wilkinson, Milliken Manufacturing Syndicate, London, announces the award to the New York house of a contract for the construction of a 112 mile, 132,000-volt transmission line to carry power from Victoria Falls to Melbourne, Australia.

C. H. Sexton formerly Operating Manager, Hattiesburg Hattiesburg Creosoting Co., has just been appointed General Manager of the Southern Paving Construction Co., Pensacola, Fla.

Hobart H. Newell formerly of the Research Laboratory, Westinghouse Electric & Manufacturing Co. is now in the Electrical Engineering Department of Worcester Polytechnic Institute, Worcester, Mass.

L. P. Dickinson who was professor of Electrical Engineering at Robert College, Constantinople, has been appointed Head of the Department of Electrical Engineering in the University of Vermont.

S. W. Fleming, Jr., of the firm of Gannett, Seelye & Fleming, Inc., has been appointed by Governor Sproul of Pennsylvania a member of the Commission to mark the battle fields of France and Belgium where Pennsylvania units fought.

Burt K. Spenser formerly Electrical Engineer with A. C. Wood of Philadelphia, is now directing the underwriting of a new line of insurance covering indemnity against burnout or breakdown of electrical apparatus for the Travelers Indemnity Company, Hartford, Conn.

W. E. Freeman formerly Supervisor of Commercial Training, Westinghouse Electric & Manufacturing Co., has been appointed Acting Dean of the University of Kentucky. Dean Anderson will also direct the work of the Research Laboratory of the American Society of Heating and Ventilating Engineers in the Bureau of Mines, Pittsburgh, Pa.

Lewis L. Ransom has resigned as Treasurer and Manager of the Bayonne branch of John R. Proctor, Inc., and is now connected with the Ransom and Anderson Co., Inc., Designing and Constructing Engineers, with offices at 136 Liberty Street, New York City, and 75 Montgomery Street, Jersey City, N. J., as Vice-President and Treasurer.

OBITUARY

Charles W. Davis, vice president and general sales manager of the Standard Underground Cable Co., Pittsburgh, Pa., died Sunday, September 11 in the Memorial Hospital, New York. He had been in failing health for several years and had gone to New York for special medical treatment. Mr. Davis was born in Pittsburgh 48 years ago and was educated at the Western University of Pennsylvania, now the University of Pittsburgh, and at the M. I. T. His connection with the Standard Underground Cable Co. began shortly after his graduation from college, or about 1899, at which time he was employed by the company as construction engineer on a large cable installation in Mexico City. Later he became Superintendent of Construction and Manager of the Central Sales Department. In 1915 he was elected Vice President in charge of the General Sales, Construction and Accessories Departments. He was well-known in the electrical industry as an expert on the design, manufacture and installation of electric cables and accessories, and had contributed largely to the development of the art by his investigations, technical papers and inventions. He had been an Associate in the A. I. E. E. since 1907.

James A. Walton, Electrical Engineering Department, Edison Electric Illuminating Company of Boston died on August 14th, 1921. Mr. Walton was born in Cambridge, Mass. in 1885. He took the electrical course at Lowell Institute. He was assistant in the electrical laboratory at the M. I. T., later went with the Consolidated Gas & Electric Light & Power Co. of Baltimore and finally with the Edison Co. of Boston in the Engineering Department. Mr. Walton joined the A. I. E. E. in 1909 and was transferred to the grade of Member in 1913.

Peter Cooper Hewitt famous scientist and inventor died on August 25, 1921 at the American Hospital, Paris, from pneumonia following an operation. He was born in New York in 1861, a son of Mayor Abram S. Hewitt of New York and grandson of the philanthropist, Peter Cooper. He was educated at Stevens Institute of Technology and received the honorary degree of Sc. D. from Columbia University in 1903 and from Rutgers College in 1916. Mr. Hewitt was probably best known through his invention and development of the mercury vapor lamp which bears his name, although the range of his efforts was extraordinary, for he accomplished results in the widely different fields of economics, physics, mechanics, chemistry, and electricity. He perfected apparatus for the wireless telegraph and telephone field, for aerating liquids, centrifugal separators, and was a pioneer in hydro-airplane and high-speed motor boat development. He was a director of the N. Y. & Greenwood Lake Ry., Cooper Hewitt & Co., Midvale Water Co. and many others. He was a Vice President of the Naval Consulting Board and a member of numerous clubs and societies among which which may be mentioned the Engineers, Players, Lambs, Union and Knickerbocker Clubs; the Society of Automotive Engineers, the Franco-American Commission, Aero Club of America, etc. Mr. Hewitt was elected to the Institute as an Associate in 1901 and was transferred to the grade of Member in 1907.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (AUG. 1-31, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

The A. B. C. of Iron and Steel

Edited by A. O. Backert. Cleveland Penton Publ. Co., 1921. 408 pp., illus., 11 x 8 in., cloth. $5.00.

This is a simple, concise yet comprehensive account of the primary processes involved in the conversion of iron ore into finished products, intended for general readers who wish a knowledge of these processes, and for technical readers wishing general information on phases of the industry outside their own experience. The book is elaborately illustrated.

Broaching Practise.

By E. K. Hammond. N. Y., The Industrial Press; Lond., the Machinery Pub. Co., Ltd., 1921. 122 pp., illus., 9 x 6 in., paper. $1.00.

For many years broaching has been used for cutting keyways and machining holes to a variety of shapes, but the method attracted little attention until comparatively recently. With the rise of the automobile industry broaching machines came into common use and now are extensively used in building many products. This book is a concise review of modern practise explaining the machines, the design of broaches and the application of the process to many classes of work.

Design and Construction of Power Workboats

By Arthur F. Johnson. Cleveland Penton Pub. Co., 1920. 113 pp., diagrams, tables, 12 x 9 in., cloth. $5.00.

The vessels considered in this volume are those propelled by internal combustion engines and intended for traversing coastwise, harbor or inland waters, embracing ferryboats for freight and passenger service, tugs, lighters, tank boats, trawlers, shop, pumping and wrecking boats. The information is given in detail and illustrated with working drawings.

Electrical Rates

By G. P. Watkins. N. Y., D. Van Nostrand Co., 1921. 228 pp., diagrams, 9 x 6 in., cloth. $3.00.

This book on ratemaking, the outgrowth of nine years experience in the statistical bureau of a public service commission is written from the viewpoint of an economist. The author has endeavored to offer a more extensive explanation and constructive application of economic principles than is customary in works on this subject and to go further into fundamental economic problems. Much space is given to the differential rate theory, to load factors and to density factors.

Electricity in Steel Works

By Wm. McFarlane. London and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's technical primers.) 109 pp., illus., 6 x 4 in., boards. $1.00.

This review of electrical practise in iron and steel works is intended for students of the steel industry and electrical engineers interested in the special conditions and requirements in steel mills. It attempts to deal with fundamental principles and practise in the generation of electricity for use in steel works, in the use of electric motors for driving rolling mills and in the use of electromagnets and electric lighting.

Heating Systems

By F. W. Raynes. Second edition. Lond. and N. Y., Longmans, Green and Co., 1921. 324 pp., plates, diagrs., tables, 9 x 6 in., cloth. $7.50.

This text book on the design of heating systems presents modern English practise. A special feature is the large number of charts that have been prepared and the method adopted for calculating pipe sizes. The practical rather than the theoretical aspects of the work have been given attention. Consideration is also given to the economical aspect of heating problems, especially in the heating of industrial buildings and plants. The new edition has been brought up to date.

Longwall Coal Cutting Machinery

By G. F. F. Eagar. London and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's technical primers.) 109 pp., illus., 6 x 4 in., boards. $1.00.

This primer is a concise review of the whole subject, with especial reference to practical aspects, and is intended to assist in the correct application of coal cutting machinery and the selection of the proper type of machine for given conditions.

Manhood of Humanity

By Alfred Korzybski. N. Y., E. P. Dutton & Co., 1921. 264 pp., 8 x 6 in., cloth. $3.00.

This book is primarily a study of man and ultimately embraces all the great qualities and problems of man. The author approaches the problem from a mathematical, an engineering

point of view, with the object of ascertaining what man's real nature is and what the basic laws of his nature are, and hopes thus to point the way to a science of directing human energies and capacities to the advancement of human welfare.

THE MECHANICAL PRODUCTION OF GOLD

By Sir J. A. Ewing. Second edition. Cambridge, University Press, 1921. 204 pp., diagrs., 9 x 6 in., cloth. $8.00. (Gift of the MacMillan Co., N. Y.)

This book contains the "Howard" Lectures delivered before the Society of Arts in 1897, as revised and reprinted in 1908. It provides a general account of refrigeration, in which stress is laid on the thermodynamic aspect of the subject, and an attempt is made to render this aspect intelligible without unnecessary mathematics. The changes in this edition are the correction of certain errata and the clearing up of some obscure points.

THE ORIFICE METER AND GAS MEASUREMENT

By Willis C. Brown and Malcolm B. Hall, Foxboro, Mass., The Foxboro Co., Inc., 1921. 112 pp., tables, illus., 8 x 5 in., cloth. $3.50.

This book, published by the manufacturers of the first commercial orifice meter, gives authentic information on orifice coefficients and their derivation, together with complete details of the mechanical construction of their own meter.

POWER FACTOR CORRECTION

By A. E. Clayton. London and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's technical primers.) 108 pp., illus., 6 x 4 in., boards. $1.00.

This little book presents the fundamental principles of power factor correction in an easily digestible form, without attempting a complete treatment of the subject. It discusses the use of static and rotary condensers and of phase advancers for improving the power factor, concentrating attention upon the principles governing their action, without attempting to describe every proposed device.

TESTING OF CONTINUOUS CURRENT MACHINES

By Charles F. Smith. London and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Pitman's technical primers.) 102 pp., illus., 6 x 4 in., boards. $1.00.

This book attempts to give in compact form an outline of the main principles underlying the practise of testing electrical machines for commercial purposes. Simplicity and emphasis on the main purposes of the tests have been the chief aim, so that much detail and many tests of limited application have been excluded. The book is intended for young engineers.

WIRING FOR LIGHT AND POWER

By Terrell Croft. Ed. 3 N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. Illus., 7½ x 5 in., cloth. $3.00.

This book is designed to fill the need for a wiring handbook that meets the requirements of the National Electrical Code, and at the same time describes and illustrates the best American practise in wiring. This edition includes a supplement covering the changes introduced in the 1920 issue of the National Electrical Code.

THE CODE AT A GLANCE

Hubert S. Wynkoop, M. E.

"The Code at a Glance" is a pocket size book with durable binding, prepared by Hubert S. Wynkoop M. E. Wherever any sort of an electrical inspection service exists—whether state, municipal or underwriters—the installation of electric wiring and appliances for light, heat or power, and quite frequently for signalling, must be performed in the manner specified in the National Electrical Code.

For twenty-five years Mr. Wynkoop has been at the head of the electrical inspection service of the City of New York, and no one appreciates better than he the need for a concise and easily consulted transcript of the Code. Consequently he has rearranged in alphabetical order all the Code requirements which it is essential for the contractor, the wireman, the estimator, and the inspector to have constantly in mind. The book is published by National Association of Electrical Contractors and Dealers, 15 West 37th Street, New York.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Portland.—June 30, 1921, University Club. Informal talk by President Berresford on the activities of the A. I. E. E., the welfare work being done and the recommendations made at the Section delegates' meeting at the Salt Lake City Convention. Attendance 25.

San Francisco.—July 6, 1921, Engineers Club. Informal dinner with President Berresford as the guest. Following the dinner President Berresford gave a very interesting talk on the status of the engineer and outlined the obligations which engineers owe the profession, and the advantages to be gained by association in an engineering society. Attendance 50.

Spokane.—June 27, 1921, Davenport Hotel. Dinner in honor of President Berresford, and a talk by him on Institute affairs in general. Attendance 20.

Vancouver.—June 3rd, 1921. Election of officers as follows: Chairman, John R. Read; Secretary, W. F. McNeill; Executive Committee, Messrs. Frannk Sawford, L. P. Philpot and T. H. Crosby. Attendance 20.

June 29, 1921, Terminal City Club. Informal dinner, followed by an open meeting at which President Berresford discussed matters of interest to the Section and the Institute as a whole. Attendance 35.

PAST BRANCH MEETING

University of California.—August 24, 1921. Election of Vice-Chairman and discussion of future program. Attendance 14.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities, is given below, together with the address as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Roy L. Ehmann, 4636 North St. Louis Ave., Chicago, Ill.
2.—Wm. J. Epps, Rua Dom Geraldo 80, Rio de Janeiro, Brazil, S. A.
3.—G. Foung, Kay Sang & Co., 843 Clay St., San Francisco, Calif.
4. W. F. Gantvoort, Kedongsarie 84, Soerabaia, Java, Dutch East Indies.
5.—T. J. Hodge, 612 West 137th St., New York, N. Y.
6.—Conrad Jacobson, Hood River, Ore.
7.—G. H. Lindsey, Rosemere Apts., 2255 West 14th St., Los Angeles, Calif.
8.—Geo. C. McCabe, 137 West 86th St., New York, N. Y.
9.—Harry P. Meyer, 327 East 61st Street, Los Angeles, Calif.
10.—Chas. Schindler, Great Western Power Co., Crockett, Calif.
11.—E. V. Stoute, 1946 Mosher St., Baltimore, Md.
12.—Frank N. Tucker, 551 East 40th Street, Chicago, Ill.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL **should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* **not** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but is received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case **and forwarded to EMPLOYMENT SERVICE, as above.**

Replies received by the bureau after the position to which they refer has been filed will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

RESEARCH ASSISTANT familar with theory of transmission lines and a-c. machinery. Must be good in mathematics and a fair mechanical designer. Will be allowed to attend a few classes in Cornell University. Location N. Y. X-894.

SALES ENGINEER experienced in belting. Must have sales experience and speak Spanish fluently. Application by letter only. X-907.

ENGINEER having ability as a correspondent, also with a full technical and practical knowledge of pumps and electric machinery as well as the application thereof, together with a personality which will qualify him for direct sales work. Application by letter only. Location Chicago. X-929.

LUBRICATING ENGINEER. Must be a graduate M. E. and able to speak Spanish fluently. Unmarried man desired on account of housing conditions. Location Philippine Islands. X-975.

HYDROELECTRIC SWITCHBOARD OPERATOR for Chile. Salary $200 per month, $50 for board. Two year contract, includes traveling expenses. If married, 3 years contract includes traveling expenses for wife. X-976.

CHIEF ELECTRICIAN for construction maintenance and repairs for mining company in Chile. Salary $300 per month, board $50 per month. Two years contract, all traveling expenses. If married a 3 years contract and wife's traveling expenses. X-977.

MECHANICAL ENGINEER well known amongst engineers, architects and contractors of New York City and vicinity to sell insulation material for manufacturing company well known in its field and well established. X-989.

SUPERINTENDENT. Age about 35. Must be experienced in rubber industry and such operations as milling, calendering and curing of rubber. Must be able to handle men to get along with them. Must be capable of taking entire charge of plant and its operations. Should be technician and be acquainted with modern practises in planning and scheduling work. X-991.

SALES ENGINEERS, preferably with some sales experience who are willing to work at the present time on straight commission basis selling motors, generators, fans, blowers, and commutator slotters and stones. Location New York City. X-1013.

WANTED: Consulting engineers experienced in building design are wanted as sales representatives in the following cities: Dayton, Columbus, Cincinnati, San Francisco, Los Angeles, Spokane, Seattle, Takoma, Toledo, Buffalo, Rochester, Atlanta, Denver, Salt Lake City, Montreal and Toronto. The work does not require a large amount of time but men of the very best calibre are absolutely essential. The sales representative must be a man who is in close touch with the building situation in his territory. Sales experience is not as important as ability to think straight. Each territory offers a splendid opportunity for the right man. X-1015.

RECENT ELECTRICAL ENGINEERING GRADUATE with two or three years sales experience for sales department of motor manufacturer. Give age, experience, and general qualifications for this work. X-1029.

ELECTRICAL ENGINEER with condenser and amplifier experience for research work on Phonodik. The condenser experience is essential. Three afternoons per week. Location New York City. X-1046.

ELECTRICAL DESIGNER who has had past experience in the design of small intricate electrical apparatus of a precision character. Location New York. X-1059.

MECHANICAL OR INDUSTRIAL ENGINEER, able to take financial interest in small but profitable manufacturing business. Able to take complete charge, relieving owners from details of management. Location, New York and Philadelphia. X-1065.

ASSISTANT SUPERINTENDENT of Power and Shops, capable of handling the work as the Supt. in his abscence, as a director of hydroelectric and steam power plants, factory electrical maintenance, machine shops, belt shop, tin shop, blacksmith shop, etc., also drafting room, employing altogether about 200 men. Position open in December. X-1076.

MEN AVAILABLE

ELECTRICAL ENGINEER, age 25, with three years experience in business and engineering including General Electric test, wishes position as assistant to active consulting engineer. Character and education the best. Available on moderate notice. West preferred. E-2968.

INDUCTION MOTOR ENGINEER. High grade electrical-mechanical engineer, age 36, with 14 years factory experience seeks opening with motor manufacturer. Knows every phase of motor game from first design to final application. Engineering records and factory processes a specialty. Salary secondary. E-2969.

ELECTRICAL ENGINEER desires opportunity to do original research work in the field of communication. Technical graduate. Has done experimental and development work in commercial electrical laboratory, also at five high-power radio stations. E-2970.

CONSTRUCTION AND MAINTENANCE ENGINEER, age 28 married. Eight years electro-mechanical construction and maintenance in large manufacturing concern. Three years superintendent of engineering on electrical, mechanical, refrigeration, steam and laboratory with same concern. Has knowledge of food chemistry. Can handle men. Can purchase and supervise stocking of all supplies. Available on short notice. E-2971.

EXECUTIVE-ELECTRICAL ENGINEER, age 36; 14 years experience in various phases of engineering and manufacturing. Would like executive position where there is an opportunity for advancement. Can handle people and get results. Present salary $4500. Good reasons for changing and can furnish references from past employers. Immediate salary not of great importance if position has future. E-2972.

EXPERIENCED ELECTRICAL ENGINEER: Technical graduate with nine years power and lighting experience in manufacturing and construction works desires executive position with engineering firm. E-2973.

SALES ENGINEER. Two years sales, six years broad electrical and mechanical engineering experience. Aggressive and resourceful. Graduate electrical engineer. Associate A. I. E. E. Age 30. Highest recommendations. E-2974.

GRADUATE ELECTRICAL ENGINEER. Age 23, single, desires connection with electric railway or power transmission construction company doing work in foreign country. South America or Asia preferred. Over one year experience G. E. test. E-2975.

ELECTRICAL DRAUGHTSMAN with 10 years experience as line foreman and telephone switchboard man; 4 years engineering experience in the design and layout of radio equipment and telephone apparatus and systems. Available at once. E-2976.

ARC WELDING machinery development position desired by technical graduate, University of Wisconsin 1918. Experience in research and development of automatic arc welding machinery; in design and manufacture of industrial motors a-c. and d-c.; and as engineer officer in U. S. Navy. Married. Salary $2600. Available Nov. 1. E-2977.

ELECTRICAL ENGINEER, Assoc. A. I. E. E., B. S. degree; unmarried; age 24; one year G. E. test; 2½ years sales engineering; desires position with reliable concern preferably in Middle West, but will go anywhere. Able to produce results in commercial engineering. Available immediately. E-2978.

ELECTRICAL ENGINEER, 1914 graduate, desires connection with consulting engineer handling public utility cases, or sales engineering position where engineering ability is of primary importance. Principal experience; one year electrical testing; 2½ years in engineering dept. of a public service commission; 3½ years in eng'g. dept. of a large oil refinery. Age 28. Married. Present salary $3000. E-2979.

ELECTRICAL ENGINEER age 28. Assoc. A. I. E. E., Jou. Mem. A. S. M. E. Chief Elec-

trician, U. S. N. 9 years service. General foreman of construction and assistant engineer in charge of construction. 10 years practical experience, 5 years d. c. and 5 years a. c. Wishes position with chance of advancement. Location anywhere. E-2980.

CHIEF ELECTRICIAN, Industrial plant, age 36, married. 16 years experience installation, operating and maintenance, d-c. and a-c. equipment. 12 years with present connection, past 9 years chief electrician. Will consider any position where chance for advancement. Location preferred east of Pittsburgh, Pa. E-2981.

RECENT GRADUATE ELECTRICAL ENGINEER, University of Michigan. Age 27. Two years practical experience with steam railroad. Position wanted with some well established electrical concern. Location U. S. Available immediately. E-2982.

JUNIOR ENGINEER OR DESIGNER. 100 per cent American, honest and trustworthy. Technical graduate (B. Sc. degree), age 24. Has had experience as electrical and mechanical draftsman and designer. Practical machine shop experience. Familiar with experimental and production developments. Expert mathematician. E-2983.

ELECTRICAL ENGINEER, technical graduate, Associate A. I. E. E. Fifteen years practical experience in quantity manufacture of small electrical and mechanical devices; electrical measuring apparatus a specialty. Designing or or developmental engineering preferred. Fully qualified for supervision of manufacturing plant of moderate capacity. Available on short notice. E-2984.

GRADUATE ELECTRICAL ENGINEER. Age 26, desires position. Has had two years design and manufacturing experience but is anxious to secure position as assistant production manager where engineering and manufacturing experience are assets. E-2985.

SALES MANAGER at present occupying this position with satisfaction to employer will consider a change. Broad experience in electrical engineering, and allied lines. Excellent sales training and record, only position of responsibility considered. E-2986.

ELECTRICAL ENGINEERING STUDENT, 5th year Cooper Union Night; age 20 years, single, three years experience in telephone maintenance, etc. Desires to hear from concerns which offer advancement and a future. Locality, New York City. E-2987.

ELECTRICAL ENGINEER, Graduate of University of Nebraska, 1916. Age 28; married. Experience: 2 years G. E. test; 18 months high-voltage underground cable and dielectric investigations; 18 months industrial application engineer, specializing on electricity in the sugar and rubber industries; also acquainted with design, appraisal and electrical contracting. Salary depends on location. Associate A. I. E. E. Available on short notice if necessary. E-2988.

ELECTRICAL ENGINEER, available for either U. S. A. or foreign service. Desirous to connect with concern with a future. Teaching experience two years, manager and foreman in electrical contracting business for the past three years. Expert on generators and motor. Assoc. A. I. E. E., age 27. E-2989.

ELECTRICAL MECHANICAL RESEARCH ENGINEER; B. S. degree; age 28; married, with six years experience in development and invention work desires position, preferably in Eastern States. Salary is not as important as opportunity to advance when ability is demonstrated. An opportunity to acquire detailed experience in electrical design is especially desired. E-2990.

ELECTRICAL AND CRANE SALES ENGINEER, 40 years old, desires position with reliable concern to develop and market any materials-handling apparatus or to sell for established concern. Have a broad active record and ambition to get ahead. Member A. I. E. E., Sigma Xi, E. K. N. Fuller information by appointment or letter. E-2991.

ELECTRICAL ENGINEER, graduate of Purdue University, married. Member Tau Beta Pi, Associate A. I. E. E. Seven years practical experience in sales, production, costs and engineering work. Would consider either practical or educational work. E-2992.

MANAGER OR SUPERINTENDENT of railway, gas, electric lighting and power properties; long experience in economical management, construction and maintenance, good on rehabilitating run-down properties; university education, married; desires a position where initiative, hard work and results would be recognized. E-2993.

SALES ENGINEER, technical graduate. Completed instruction course with Cutler-Hammer Mfg. Co. Successful sales experience in district office. Wish to represent a well known concern on a salary and commission basis. E-2994.

MANAGER, Electrical Engineer, thoroughly experienced in public utility management and operation of steam and hydroelectric plants and railways. Versed in technical and engineering details, and in office management. Tactful and successful in dealing with public. Available at once. E-2995.

ELECTRICIAN, married, 26. Californian, returning to Oakland, available January 1, 1922. Practical eight years' experience including navy, factory test of industrial heating and controlling appliances, maintenance of axle lighting and storage battery equipment. Capable of handling men. Prefer position in charge of factory, power plant, in vicinity of San Francisco Bay cities. Best of references. E-2996.

ENGINEER, sixteen years experience in design and manufacture of direct and alternating-current motors to one hundred horse power. Have developed number special motors for application to various classes apparatus. Appreciate value of simplicity of mechanical design in relation manufacturing costs. Considerable executive and sales experience. E-2997.

ELECTRICAL ENGINEER, technical graduate, age 30 years. Assoc. A. I. E. E. Four years experience in testing, construction and maintenance. Location, east of Mississippi River. Available immediately. E-2998.

CHEMICAL ENGINEER, 1917, four years experience in electrical laboratory of large brass company, on a most varied line of work, ranging from the setting up of production tests of small motors to the development of intricate and novel relays. A position of responsibility is desired, preferably in Philadelphia or vicinity. E-2999.

CONSTRUCTION SUPERINTENDENT OR ASSISTANT ENGINEER, on power house or transmission line construction or operation. Sixteen years experience in electrical work, including five years as chief operator of power company. Desires to get in touch with engineering companies engaged in development work in Central and South America, chiefly along hydroelectric lines. E-3000.

ELECTRICAL ENGINEER, technical graduate, with broad business, sales and executive experience, desires situation with central station, consulting or contracting engineer, or with manufacturer or export company. Six years in Mexico, five years with Westinghouse company in engineering dept. Age forty. E-3001.

ELECTRICAL AND MECHANICAL ENGINEER, graduate, 5 years experience including G. E. electrical and turbine test; Electrical Expert Aide U. S. Navy Dept., Experimental and test engineer for turbine manufacturer; at present making special power studies; desires position with manufacturing concern or as maintenance engineer or with power company. Will also consider foreign service. Married, 29 years of age. E-3002.

EXECUTIVE with the management viewpoint. 14 years experience in construction operation and management of public utility properties. Trained in engineering and higher accounting. Has filled positions as resident engineer, superintendent, controller and general manager. At present with large engineering concern. Age 34. Salary six thousand. E-3003.

ELECTRICAL ENGINEER, age 26, college graduate, (U. S. A.) with one year of post graduate work in Sweden, desires position, preferably with hydroelectric company, but will consider any position with opportunity for advancement. Experience includes some high-voltage test work, installation of small apparatus and general wiring. E-3004.

POWER PLANT ENGINEER, age 34, competent trustworthy, technical training. Experience, steam and hydroelectric operation and maintenance covering eight years. Six years' experience as chief electrician. Desires position with company offering permanent employment with future opporunity for advancement. Location, Michigan or nearby preferred. Assoc. A. I. E. E. Available immediately. E-3005.

ELECTRICAL ENGINEER, Technical Graduate, age 25. With executive and business ability, desires to connect with small utilities company. Capable of managing same. Three years experience on transmission, distribution, operation and power contracting, one year on G. E. test. Six months power plant experience. Single, energetic. Location immaterial, available in two weeks. E-3006.

ELECTRICAL ENGINEER, Missouri University 1912, electrical testing two years, general engineering, including sales engineering (manufacturing and public utilities) three years. Transformer and a-c. motor designing four years. Also teaching experience in mathematics and electricity. Location St. Louis or vicinity. Salary $3000. E-3007.

STEAM-ELECTRIC PLANT ENGINEER. Technical graduate, seven years with General Electric Co. in test, laboratory, design, developmental and commercial work. Three years steam plant testing and engineering. Familiar with oil burning boiler room practise and various metering devices of a modern steam turbine plant. Prefer power plant work. E-3008.

ELECTRICAL ENGINEER, age 31 years, married, desires position on railroad, electrification project, or as works engineer in industrial concern. Previous experience; electrical testing, public-utility appraisal and construction-inspection, army officer, drafting and designing in rubber manufacturing plant. Location preferred, Chicago or mountain West. Two weeks notice. E-3009.

FACTORY EXECUTIVE, age 35. Electrical and Mechanical Engineer 15 years' experience in the operation of industrial power plants and in factory management. Last 5 years, production manager in large factories manufacturing electrical machinery and automobile engines. Available Oct. 1. Location immaterial. Opportunity not salary is prime consideration. E-3010.

ELECTRICAL ENGINEER, B. S. degree Age 23, single. Desires position with power or manufacturing concern, also had four years experience at the tool and die making line. Location in the East preferred. Available at once. E-3011.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1921.

Barnes, Lynn G., Schenectady, N. Y.
Barrett, Arthur C., Las Cruces, New Mexico.
Barron, Frederick H., Amsterdam, N. Y.
Baskin, John P., Atlanta, Ga.
D'Andrea, Michael E., Rockville Centre, N. Y.
Dohl, Alfred P., E. St. Louis, Ill.
Eckles, Fayette B., Kansas City, Mo.
Elznic, Felix F., New York, N. Y.
Emmons, Norman E., (Member), Hartford, Conn.
Fossatti, P. G., Jay, Maine.
Gibbon, Thomas H., Toronto, Ont.
Glass, Paul W., New York, N. Y.
Grabe, Clarence G., (Member), Pittsburgh, Pa.
Harty, Edgar A., New York, N. Y.
Holladay, Collis H., Los Angeles, Cal.
Hoxie, Harvey H., San Francisco, Cal.
Hoyle, Bernard C., Lynn, Mass.
Johnson, Martin A., St. Joseph, Mo.
Klapholz, Maurice, Harrison, N. J.
Matz, Charles, Hammond, Ind.
McGinty, Ernest A., San Francisco, Cal.
McMann, Renville H., New York, N. Y.
Newcomb, Harry F., Pittsburgh, Pa.
Pestel, Arthur, New York, N. Y.
Rathgeb, Charles C., Three Rivers, Que.
Scribner, Elmer B., New York, N. Y.
Sery, Ralph J., Monroe, Wisconsin
Shea, Thomas F., Pittsburgh, Pa.
Silent, Harold C., New York, N. Y.
Soares, Eustace C., New York, N. Y.
Stowers, Addison C., Pittsburgh, Pa.
Talley W. E., Trenton, N. J.
Taylor, Orson H., Toledo, Ohio
Thomas, George D., Gilboa, N. Y.
Towne, Roger P., Boston, Mass.
Van Rosen, Hugo, (Member), Boston, Mass.
Whitesell, Frank E. Lloyd, Boston, Mass.
Total 37.

Foreign

Agarwala, Munnalal C., Cawnpore, India
Butler, William C., Santiago, Chile
Geenens, Leo, (Member), Havana, Cuba
Hall, Ernest, Capetown, S. Africa

OFFICERS OF A. I. E. E. 1921-1922

President

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Junior Past-Presidents

CALVERT TOWNLEY — A. W. BERRESFORD

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L. F. MOREHOUSE	HARLAN A. PRATT

Treasurer GEORGE A. HAMILTON

Secretary F. L. HUTCHINSON

A. I. E. E. COMMITTEES

(A list of the personnel of Institute committees will be found in the September issue of the JOURNAL, and will be published again in the November issue.)

GENERAL STANDING COMMITTEES AND CHAIRMEN

EXECUTIVE, William McClellan
FINANCE, L. F. Morehouse
MEETINGS AND PAPERS, E. E. F. Creighton
PUBLICATION, A. S. McAllister
COORDINATION OF INSTITUTE ACTIVITIES, W. I. Slichter
BOARD OF EXAMINERS, H. H. Norris
SECTIONS, A. W. Berresford
STUDENT BRANCHES, C. Francis Harding
MEMBERSHIP, E. H. Martindale
HEADQUARTERS, W. A. Del Mar
LAW, H. H. Barnes, Jr.
PUBLIC POLICY, H. W. Buck
CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT, C. A. Adams
SAFETY CODES, H. B. Gear
STANDARDS, Harold Pender
EDISON MEDAL, C. A. Adams
RESEARCH, F. B. Jewett

TECHNICAL COMMITTEES AND CHAIRMEN

EDUCATIONAL, C. E. Magnusson
ELECTRICAL MACHINERY, B. A. Behrend
ELECTROCHEMISTRY AND ELECTROMETALLURGY, Lawrence Addicks.
ELECTROPHYSICS, F. W. Peek, Jr.
INDUSTRIAL AND DOMESTIC POWER, W. C. Yates
INSTRUMENTS AND MEASUREMENTS, F. V. Magalhaes
IRON AND STEEL INDUSTRY, E. S. Jefferies
LIGHTING AND ILLUMINATION,
MARINE, Arthur Parker
MINES, Graham Bright
POWER STATIONS,
PROTECTIVE DEVICES, H. R. Woodrow
TELEGRAPHY AND TELEPHONY, Donald McNicol
TRACTION AND TRANSPORTATION, H. M. Brinckerhoff
TRANSMISSION AND DISTRIBUTION, Edward B. Meyer

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the JOURNAL and will be published again in the November issue.)

COUNCIL OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
AMERICAN BUREAU OF WELDING
AMERICAN COMMITTEE ON ELECTROLYSIS
AMERICAN ENGINEERING COUNCIL OF THE FEDERATED AMERICAN ENGINEERING SOCIETIES
AMERICAN ENGINEERING STANDARDS COMMITTEE
BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY
ENGINEERING FOUNDATION BOARD
FRANCO-AMERICAN ENGINEERING COMMITTEE
JOHN FRITZ MEDAL BOARD OF AWARD
LIBRARY BOARD, UNITED ENGINEERING SOCIETY
ELECTRICAL COMMITTEE, NATIONAL FIRE PROTECTION ASSOCIATION
ENGINEERING DIVISION, NATIONAL RESEARCH COUNCIL
U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION
U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION
COMMISSION OF WASHINGTON AWARD

A. I. E. E. SECTIONS AND BRANCHES

A complete list of the 42 Sections of the Institute, with the names of the chairmen and secretaries, may be found in the September issue of the JOURNAL and will be published again in the November issue. A list of the 61 Branches will be published in the November issue.

ADDRESSES FOR 1922 YEAR BOOK.

TO THE MEMBERSHIP:

It will be appreciated if those members who are not certain that they have notified Institute headquarters of any change in business or mailing address made during the present year, will submit the information called for below at the earliest possible date.

F. L. HUTCHINSON,
Secretary

Title or occupation ....

Company or business address ....

....

Residence address ....

Mailing address for publications ....

Signature of member (in full) ....

Date..............................

JOURNAL
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Vol. XL NOVEMBER, 1921 Number 11

Electric Propulsion of Ships

BY W. E. THAU

Marine Department, Westinghouse Electric and Manufacturing Co.

THIS paper deals primarily with the electric propulsion of ships, except wherein a comparison of some particular feature or characteristic warrants a reference to some other type of drive. In dealing with electric propulsion, it is necessary to consider all classes of ships, and this leads to two broad, general classifications, such as merchant ships and war vessels.

Merchant Ship Propulsive Equipment

General Requirements

The ultimate purpose of a merchant ship is to earn money. From this standpoint, the factors of reliability, economy, weight, space, cost, operation and maintenance are involved in the propulsive equipment. Therefore the type of drive most suitable is that which excels in all or the most important of these factors. The relative importance of these items varies with different ships, depending upon the trade route, cargo, etc., with the result that there is a definite and logical field for each of the principal types of drives, such as reciprocating engine, geared turbine, turbine-electric, Diesel and Diesel-electric. Since many general comparisons of the principal types of drives in regard to these factors have been given in recent articles in the technical press it is not the intent of the present paper to take up this phase of the subject, but rather to analyze the principal types of electric propulsive equipments and to show in general how they fulfill these requirements.

Reliability

The universal use of, and the indisputable success of electrical apparatus on land is sufficient testimony in behalf of its reliability. The absence of reciprocating parts makes electrical apparatus with its simple rotation as reliable as can be desired. It can almost be said that there are no mechanical troubles with electrical machinery. Broadly speaking, there are no new principles involved in the application of electrical apparatus to ship propulsion. It is true that ship conditions differ from land conditions in certain respects, but there is no phase of the application which presents any really serious difficulty. The most important adverse condition is the deleterious effect of salt and moisture, which is easily surmounted by proper insulation of the windings and circuits, as is obvious from the several years of successful operation of present electric propulsion equipments. There can, therefore, be no question as to the reliability of electrical propulsive equipment.

Economy

Economy is an important factor, and must be given due consideration. To properly analyze this item, it is necessary to consider all equipment involved in the propulsion, with respect to fuel, water, lubricants and supplies. The relative proportions of these items vary considerably in the different types of propulsive equipments. The turbine-electric and the geared turbine compare very closely in economy when all items are considered. The losses in the reversing elements of geared turbines, the losses in the gears and the power required to circulate the additional lubricating oil, detract appreciably from the gain which the geared turbine would otherwise have over the turbine-electric because of the inherent electrical losses in the latter. Generally speaking, the net economy of a properly designed and constructed geared turbine drive should be better than a turbine-electric drive, even though full advantage is taken of every practical source of gain in the latter. The difference, however, is perhaps hardly of sufficient magnitude to be the dominating factor in arriving at a final selection. The economy of a reciprocating engine drive is obviously poorer than that of a properly designed turbine drive of either type for the reason that the reciprocating engine cannot utilize the same expansion of the steam.

It has been advanced that the turbine for the turbine-electric system, being a one-direction rotation machine, can utilize higher superheat than the geared turbine, because of the reversing element of the latter, thus resulting in better overall economy. With the present installations, this condition is true to some extent. However, with proper attention given to this factor, geared turbines can be designed to operate without detriment with steam superheated 150 to 200 deg.

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fahr., which is fairly close to the practical limit of superheat on board ship, as there are other items aside from the turbines which are affected by high superheats to the extent of fixing limitations.

Obviously from a fuel consumption standpoint, the direct Diesel and Diesel-electric propulsive equipments offer by far the best economy. Of these two types, it would appear, offhand, that the direct Diesel drive is decidedly superior to the Diesel-electric; however, it will be shown later that there are certain limitations in the direct Diesel drive which offset its advantage in fuel per brake horse-power-hour over the Diesel-electric. Here again, it is obvious that all items related to the propulsive equipment must be taken into consideration to obtain the ultimate answer.

Weight

The item of weight would probably show more variance than other items owing to differences of arrangement, design, foundations, etc., in the practise of the several ship builders. The importance of weight depends upon the type of ship, cargo, and trade route. Usually, however, weight is an important item as it has a direct effect upon the total fuel consumption and the amount of cargo that can be carried with a given displacement. Here again, it is necessary to consider all items related to the propulsive equipment. A correct comparison of weight necessitates that the equipments under consideration be on the same basis relative to overload, factor of safety and arrangement. This is particularly important in comparisons between electric drive equipments. Where one equipment affords an advantage in flexibility of reserve, however, it is usually at some sacrifice in weight, and an allowance must be made.

Space

Space is important in that it has a direct bearing upon the bulk of cargo that can be carried. Its relative importance depends somewhat upon the location of the machinery, *i. e.*, whether the machinery is located amidship or aft, or both. Space is affected by the distribution of machinery and the relative saving depends somewhat upon the practise of the various ship builders in that respect. General analysis of the space factors which have been made thus far gives the advantage to the direct-connected Diesel and Diesel-electric types of propulsive equipment, the saving being effected by the elimination of the boilers and reduction of fuel and water tanks. Of the turbine-electric and geared turbine types, the space factor is in favor of the geared turbine, except in special cases. The general arrangement of the engine room, number of propellers and the beam of the ship have a direct effect upon the space occupied as a result of machinery distribution. By locating the condensers underneath the turbines in electric drives, the total floor space can be greatly reduced.

Cost

A definite comparison of costs is still a difficult task owing to the continued unsettled conditions. On the basis of equal performance in regard to propeller torque and speed, the cost including all items related to the propulsive equipment should run in the order of direct-Diesel, turbine-electric, geared turbine, and Diesel-electric, the latter being the cheapest. The paradox in the relative cost of direct-Diesel and Diesel-electric is explained by the condition that small Diesel engines and generators for Diesel-electric drives can be manufactured ultimately on a large production basis and stocked, whereas the engines for direct-Diesel drive, and to a large extent, the two types of turbine drive, because of their large size and weight, must almost of necessity be a building proposition. On the basis of standardized drives, there should not be a great deal in favor of the geared turbine as compared with the turbine-electric drive. This comparison will vary somewhat with the different manufacturers.

The initial cost of the propulsive equipment has a direct effect upon the net earning power of the ship, because of interest, depreciation and insurance charges, and therefore, cost is an important item.

Operation

In regard to operation, it is realized that the present operators are largely men who are more familiar with reciprocating engines than with other types of machinery, and that for this reason, certain difficulties are likely to be encountered in placing electrical equipments in their hands. The author believes that this thought should not be a consideration, as it is a temporary condition only. The horse car driver became the motorman of the electric car, the reciprocating plant operator became the turbine plant operator in the central station, the steam locomotive engineer became the electric locomotive engineer (engineers now operating electric locomotives are reluctant to return to the steam locomotive), and similarly countless examples may be mentioned to show that change in machinery represents no obstacle. Successful operators of electrical machinery need not have sufficient knowledge of it to understand the details of its design. This is not the case on land and there is no greater reason for it on the sea. The operator should, however, know the operating characteristics of electrical apparatus and how to take care of it.

The same question was raised in the case of geared turbines only a few years ago, yet today there is nearly a sufficient number of competent geared turbine operators to take care of all the geared turbine ships. The same will be the case with operators for electric ships. It is merely a matter of training and education and it is certainly a reflection upon the intelligence of the age to classify the present limited knowledge as an obstacle for consideration.

The following is a probable list of the operating

personnel for the principal types of drives. The cost of operating personnel as based upon this list would, therefore, be in the order of,—direct-connected Diesel, turbine-electric, geared turbine, reciprocating engine, and Diesel-electric:

TABLE OF PROBABLE OPERATING PERSONNEL.

		Reciprocating engine	Geared turbine	Turbine electric	Direct connected diesel	Diesel electric
		*	*	*		
Total Crew	Chief	1	1	1	1	1
	1st. Asst	1	1	1	1	
	2nd. Asst	1	1	1	1	1
	3rd. Asst	1	1	1	1	1
	Jr. Engrs	0	0	0	3	0
	Electricians	0	0	1	1	1
	Oilers	3	3	3	6	6
	Firemen	6	6	6	0	0
	Total	13	13	14	14	1[illegible]
On each watch	1st., 2d or 3d	1	1	1	1	1
	Junior Engrs	0	0	0	1	0
	Electricians	0	0	0	0	0
	Oilers	1	1	1	2	2
	Firemen	2	2	2	0	0
	Total	4	4	4	4	3

*Based on oil burning ships. For coal ships, the operating personnel would be augmented by three coal passers.

Maintenance

Although there are practically no data available on the maintenance of electrical propulsive equipments (except battleships), there is no reason to anticipate any great difference between sea and land practise. As a matter of fact, there is reason to anticipate less maintenance for the reason that the load conditions and control operations are less severe than is the case with most land installations involving large machinery. If the equipment is given proper care and inspection, the maintenance item will be low, as the absence of rubbing parts (except for the bearings), leaves little to get out of order. Electrical machinery does not wear as is the case with other machinery. Furthermore, all probable repairs are such as can be made aboard the ship without the use of an elaborate machine shop.

Performance Characteristics

The inherent performance characteristics of electrical machines are particularly well suited to ship propulsion. Having identical operating characteristics in either direction of rotation, all types of electric drive inherently afford, or can be made to afford, full torque and power for reversal. For reasons of economy, space and cost, the reversing element of a geared turbine is designed to give only 40 per cent to 60 per cent power in the reverse direction. It has been claimed that full reverse power is not essential to a merchant ship, and this is true under ordinary conditions. In emergency, however, it is desirable to stop the ship very quickly, and in this connection it might be pointed out that the electric ship can be stopped in considerably less time than a geared turbine ship. This is not altogether the result of less backing power, but is due to a great extent to the inefficiency of the reversing element of the geared turbine causing an enormous draft on the boilers which greatly reduces the steam pressure.

In reversing, the energy put into the screws by the action of the water and the stored energy in the rotating parts attached to the propeller shaft, must be dissipated in some manner. In the case of the geared turbine, this energy is consumed in doing work on the steam. In the case of a-c. electric drives, the energy of reversal is dissipated in the motor and generator windings, the rotors of the motors, or in external resistors connected to the rotor circuits, depending upon the type of motor used. In d-c. electric drives, the reversal energy must be absorbed elsewhere in the system. The amount of energy to be dissipated or absorbed in the case of a given ship depends entirely upon the time taken to stop the screws. The instant the screws commence to turn over in the reverse direction, the system must supply the energy and all further stopping energy is dissipated at the propellers. There are two factors to be considered in stopping, namely, the energy returned through the propellers, and the stored energy in the propellers and the motor armatures. Analysis shows that reversing even at full speed is not a serious problem, and that it does not place as severe requirements upon the electrical machinery as does turning with hard-over rudder. The details of the distribution and absorption of the energy of reversal would occupy too much space to be discussed at this time. Suffice it for the present to say that the inherent facilities afforded by electrical systems for dissipating energy and for giving full power in either direction are what make the electric drives ideally suited for stopping. The time required to stop an electric ship is the same as, or less than, that of other drives.

Description of Electrical Propulsive Equipments

General Classification

Electrical systems for ship propulsion may be classified into two general types from the standpoint of the prime movers, namely, turbine-electric and Diesel-electric. Due to the inherent performance of these two types of prime movers, both kinds of electric machinery are used; a-c. machinery with turbine-electric because the a-c. generator is inherently suitable for direct connection to the economical high-speed turbine; and d-c. machinery with Diesel-electric drive because the inherent characteristics of the d-c. generator are ideally suited to Diesel engine performance.

The electrical equipment for turbine-electric drive may be further sub-divided as follows, in regard to the type of motor:

1 Induction
- Wound secondary
  - Ordinary, and with power factor correction
- Squirrel cage
- Combined squirrel cage and wound secondary

2 Synchronous

In the case of the Diesel-electric drive, there is no broad subdivision. As a minor classification, this type of drive might be subdivided with respect to the method of generator operation, *i. e.*, series and parallel. However, series operation is so vastly superior that parallel operation can be disregarded except for the purpose of comparison.

Units Involved

A complete turbine-electric drive involves the following apparatus:

Boiler plant	Motor
Evaporation plant	Oiling system
Condenser plant	Exciter set
Turbine	Control
Generator	

A complete Diesel-electric drive involves the following apparatus:

Diesel engines
Generators
Motors
Small auxiliary air compressors
Air bottles
Exciters
Fuel pumps, (if not attached to engine)
Lubricating pumps, (if not attached to engine)
Control

Turbine-Electric

With turbine-electric drive, the electrical equipment is of the a-c. type, principally for the reason that a-c. turbo generators are inherently better suited for the high economical speeds of turbines. The speed at which the turbine operates is influenced by the propeller speed because of the limitation in the number of poles of the motor. Theoretically, an a-c. motor can be built for any even number of poles, but in practise such factors as power factor, (induction motor), diameter and assembly, fix the limit in the neighborhood of 60 to 72 poles. As the motor speed and numbes of poles fix the generator and turbine speed, there ir consequently an approximately fixed limit to turbine speeds. Incidentally, in the case of practically all merchant ships, this speed is lower than the most economical speed of the turbine. As the propeller is most efficient when designed and operated at low speeds, it is advisable not to exceed 90 to 100 rev. per min. for the ordinary merchant ship.

Assuming a propeller speed of 100 rev. per min., a 60-pole motor and a two-pole generator, the generator and consequently the turbine would operate at 3000 rev. per min. (neglecting the slip in case of the induction motor). This gives a reduction from the turbine to the propeller of 30:1, which is approximately the same irrespective of the type of motor used.

Fig. 1 shows a diagrammatic scheme of connections for an induction motor drive of the wound secondary type. Power is supplied from the turbine-driven generator to the induction motor through one of the reversers. The generator is excited from one of the auxiliary geared turbine d-c. sets. Whether the auxiliary set would supply generator excitation only, or simultaneously furnish ship's auxiliary power, depends principally upon the electrification of engine room auxiliaries, winches, etc.

The turbine is under the control of a governor capable of maintaining constant speed over about 75 per cent of the entire speed range. The governor speed control valve is regulated from the control stand by an oil relay valve or system or rods and levers, depending upon the type of governor used. The propeller speed is adjusted by throttling the turbine as

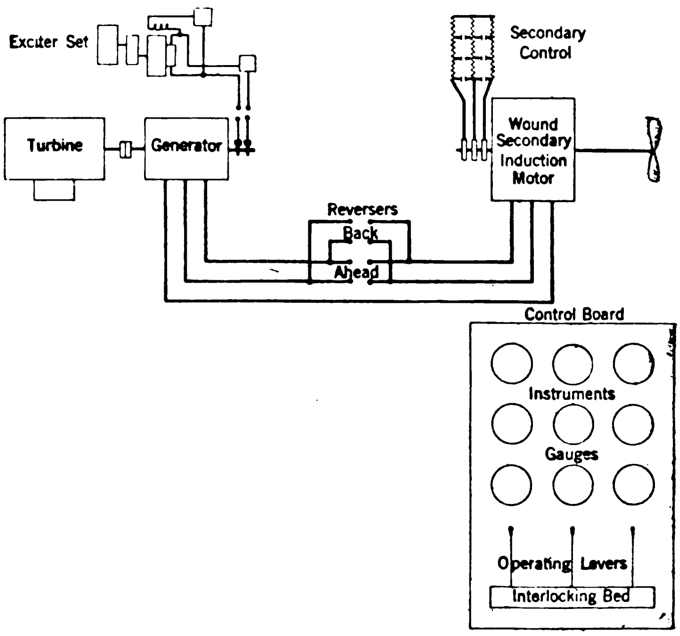

Fig. 1—Wound-Secondary Induction-Motor Drive
Diagrammatic scheme of connections.

in the case of a geared turbine drive. The turbine is started and brought up to its "idling speed" by the throttle valve at the turbine.

Similarly, the generator field switch and rheostat, and the ahead and back switches are controlled from the control stand by means of levers. These levers are mechanically interlocked so that it is necessary to follow the proper sequence of operations in starting, stopping and maneuvering.

Usually, the reversers are interlocked with the field lever so that the field lever must be in the "off" position before the reversers can be opened or closed. Similarly the field is interlocked with the turbine speed control lever so that the control valve must be set for low speed before the field can be opened or closed.

The secondary control is automatic, being either of the solenoid contactor or motor-operated contactor

type. The actuating means is energized through contacts on the field lever near the end of its stroke. This arrangement insures the establishment of voltage at the motor before closing the secondary accelerating switches. Similarly, moving the field lever to the "off" position, opens the secondary switches.

The operating levers and a complete complement of electrical instruments and steam gages are arranged convenient to the operator, the instruments and gages being mounted on a panel directly above or in front of the levers. By observing the instruments, the operator will be kept informed at all times of the performance of all machines, even though the machines be obscured from his view.

By a suitable arrangement of the switches and control levers, the entire maneuvering of a ship of any size and any number of screws, can be under the complete control of one operator.

The interlocking system necessitates the following sequence of operation:

A—Starting Ahead (Turbine Idling):

1. Close Reverser in "Ahead" position,
2. Close Field and establish excitation,
3. Adjust Turbine Speed to desired value after secondary is completely short-circuited. (Indicated by pilot light)

B—Stopping:

1. Move Turbine Speed control lever to idling position,
2. Move Field lever to "off" position.
3. Move Reverser to "off" position.

C—Starting Back:

1. Close Reverser in "Back" position,
2. Close Field and establish excitation,
3. Adjust Turbine Speed to desired value after secondary is completely short-circuited.

D—Reversing (From Ahead Operation):

1. Move Turbine Speed control lever to idling position,
2. Move Field lever to "off" position,
3. Move Reverser from "Ahead" to "Back" position,
4. Move Field lever to full excitation,
5. Bring up Turbine Speed after motor has pulled into step.

The above description applies to a single-screw drive having but one turbine set. For a multiple-screw ship having generating sets for port and starboard sides, the operation would be the same for each side of the ship, as just described.

The above operations are based upon switching when the current in the circuits has been reduced to very low values, or nearly dead circuit conditions. This arrangement is not really necessary, as, with small powers, it is is not essential to open the generator field; however, it may be justified in the light of conservatism. In any event, the reversers are so designed that they are entirely capable of opening full power.

The salient features of the wound-secondary-induction-motor drive are its inherent torque characteristics and the ease of handling. While the secondary control necessitates a few additional switches, this is fully compensated for by the fact that the propeller energy of reversal, and the slip energy of reversal and starting is dissipated in resistors external to the motor. The importance of this is dependent upon the amount of reversing that is done, particularly from full speed. This system, therefore, represents the most conservative arrangement of turbine electric drive.

The squirrel-cage motor system is shown in Fig. 2, and it will be noted that the electrical connections are the same as for the wound-secondary motor system, except that there is no secondary control. This system is, therefore, somewhat simpler than the wound-secondary motor system from an electrical connection standpoint, both inside and outside the motor. It also has a slight advantage in cost in that the motor is less expensive to build. The squirrel-cage motor is shorter because of the absence of collector rings. It has a disadvantage in conservatism and torque characteristics.

The power factor of either of the induction motor systems is less than unity, the exact value depending

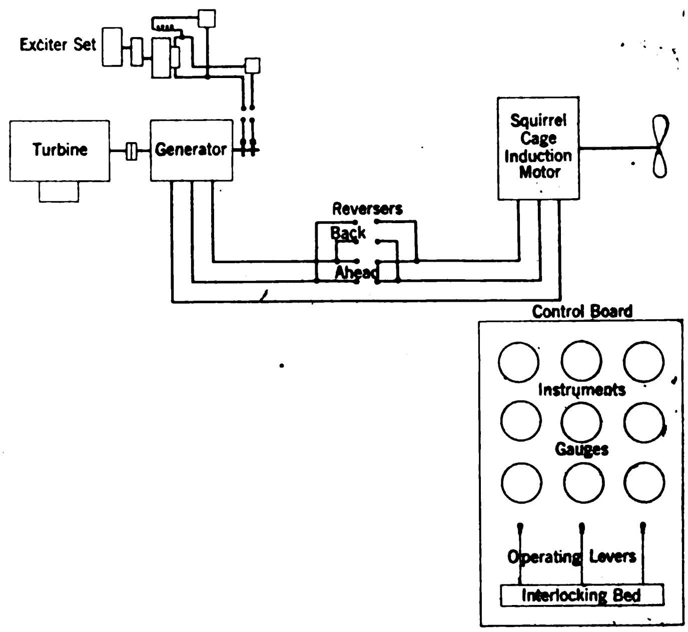

Fig. 2—Squirrel-Cage Induction-Motor Drive
Diagrammatic scheme of connections.

upon the number of poles and certain design features. For the ordinary merchant ship requirements, these motors would have power factors of approximately 70 per cent, the wound-secondary motor having the higher power factor of the two, by a small amount. The induction motor drive, therefore, requires a generator with kv-a. capacity in excess of its kw. capacity, which adds somewhat to its weight and size, and which detracts a very small amount from its efficiency.

The efficiency of the squirrel-cage induction motor of ordinary design is slightly less than that of the wound-secondary motor, for the reason that sufficient permanent resistance must be incorporated in the rotor windings to obtain the required torque for reversal without excessive current. In large motors with special double secondary windings, the required torque can be obtained without excessive current and the

running efficiency can be improved somewhat. Such motors are in use on propeller drives at the present day.

Turbine Electric
(Synchronous)

Fig. 3 shows a diagrammatic scheme of connections for a synchronous motor drive. Power is supplied from the trubine-driven generator to the synchronous motor through one of the reversers. The generator and motor fields are excited from a three-wire, d-c. exciter set. The synchronous motor system differs from the induction motor system only insofar as the synchronous motor itself affects the details of control and generator capacity, the main features of turbine-electric drive being otherwise the same.

Although the characteristics of the ordinary synchronous motors are not suitable for ship propulsion, the synchronous motor can be modified to give characteristics which meet the requirements. The modification consists in providing the rotor with a substantial induction winding of such design and arrangement as will not seriously detract from certain purely synchronous motor characteristics which are desirable.

The maneuvering operations can be accomplished in more than one way. If appreciable torque is required to reverse, the method which appears to be most favorable is to utilize the synchronous characteristics and the induction characteristics at different stages of the reversing cycle. The motor is stopped as a synchronous generator loading into the generator windings which form a dead load (generator field not being excited), then is brought up to nearly synchronous speed in the reverse direction as an induction motor, and finally is pulled into step with the generator as a synchronous motor. With this method, the sequence of operation for reversing would be approximately as follows:

1. Reduce turbine to idling speed (25 per cent.)
2. Open generator and motor fields,
3. Reverse motor connections,
4. Apply motor field excitation bringing motor to rest,
5. De-energize motor field,
6. Energize generator field to double value, bringing motor to nearly synchronous speed as induction motor,
7. Apply normal excitation to motor field, pulling motor into synchronism with generator,
8. Adjust speed to desired value.

The method described above is preferable where appreciable torque is required during reversing. Usually, however, sufficient torque will be developed by the simpler method of reversing as an induction motor, in which case the cycle of operation will be as follows:

1. Reduce turbine to idling speed (25 per cent),
2. Open generator and motor fields,
3. Reverse motor connections,
4. Energize generator field to double value, bringing motor to rest and reversing it to nearly synchronous speed, as an induction motor,
5. Apply normal excitation to motor field, pulling motor into synchronism with generator,
6. Reduce generator field to normal,
7. Adjust speed to desired value.

This method, therefore, simplifies the sequence to the extent of omitting one step and eliminating the generator action of the synchronous motor.

Although eight and seven steps respectively have been indicated in the sequence, some of the steps can be combined so as to reduce the actual number of lever operations to a reasonable amount.

Although the synchronous motor requires special design and introduces additional complications in the control, it has the important inherent characteristic of unity power factor. The unity power factor results in slightly decreased weight and size, and consequently less cost of the motor and generator. Taking the drive as a whole, and considering that both motor and generator must be excited from a separate source at a cost of at least twice the steam per kw-hr. as the main turbine, the efficiency improvement over the induction motor drive is more apparent than real. Therefore, the principal advantages of the synchronous motor drive as compared with the ordinary induction motor drive are a slight saving in cost, weight and space, with a possible inappreciable margin in efficiency.

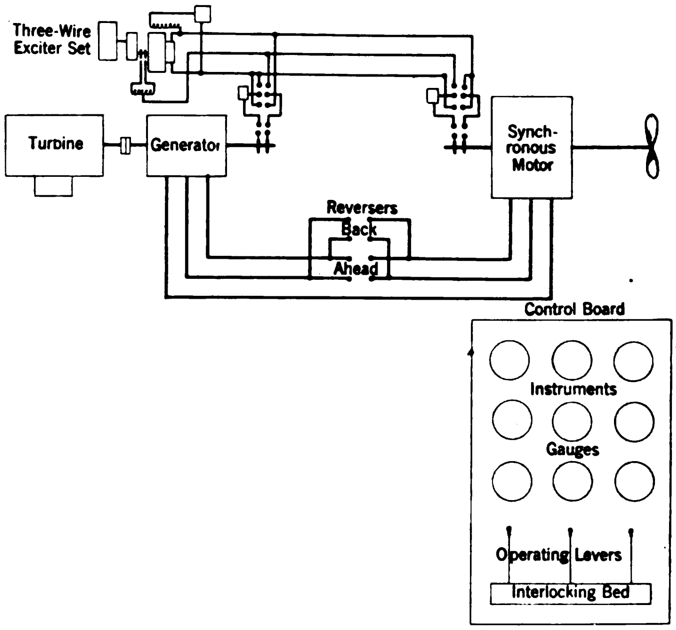

Fig. 3—Synchronous Motor Drive
Diagrammatic scheme of connections.

Turbine Electric
(Induction with Power Factor Correction)

The unity power factor advantage of the synchronous motor system is also available with a wound-secondary induction motor system in which the low lagging power factor is corrected to unity. This arrangement not only provides a system of the same weight, space and cost of the synchronous system, but in addition possesses the superior torque characteristics and simplicity

of control of the wound-secondary induction system.

The diagrammatic scheme of connections is shown in Fig. 4. It will be noted that this is the same as the wound secondary induction motor system shown in Fig. 1, except that power factor corrective apparatus has been added. The scheme functions in the same manner and sequence as that shown in Fig. 1 until the motor is in step with the generator, and at this point the power factor corrective apparatus is caused to function. The corrective apparatus consists of a Le Blanc phase advancer driven by a small d-c. motor, the speed of which may be varied to suit the power factor correction desired. The function of the phase advancer is somewhat similar to that of the d-c. exciter in the case of the synchronous motor in that it supplies excitation to the induction motor. The connection is made to the secondary or rotor winding and thus excitation is supplied through the secondary instead of through the primary, with the result that the primary current is all "power" current, which means "unity" power factor.

The phase advancer is a small commutating machine of very simple construction. The losses in the phase advancer consist of the internal copper loss due to the secondary current, almost negligible iron losses, friction, windage and brush drop. The total of these losses is very little and compares very favorably with the excitation power of the synchronous motor.

The induction motor used with this system is simple in construction, smaller, lighter and consequently less expensive than the motor used with the ordinary wound-secondary induction motor system. The generator is the same as that for the synchronous motor drive. Thus, the induction motor drive with the phase advancer not only provides the advantages resulting from unity power factor, but in addition provides the superior torque characteristics of the wound-secondary induction motor for maneuvering, and also obviates the necessity for synchronous operation with the generator. In fact, it combines all the desirable features and characteristics of both systems, without complications.

Diesel-Electric

For practical reasons, direct current only is feasible with Diesel-electric drive. This will be evident by a proper analysis of the performance of Diesel engines in connection with the characteristics involved in applying a-c. and d-c. machinery, due consideration of ship requirements being taken into account. To obtain the best results with Diesel-electric drive, it is necessary to provide several relatively small and moderately high-speed generating sets for supplying power to single or double-unit direct-connected propelling motors. Not only must the generated power divide evenly or proportionately between the generating units, but the system must also be such as will conveniently and economically lend itself to speed control.

In the case of alternating current, it would be necessary to operate the generators in parallel. To operate a-c. generators in parallel necessitates the very closest speed regulation and practically identical angular velocities of all prime movers. To visualize properly this exacting requirement, it must be remembered that satisfactory parallel operation of a-c. generators necessitates that the angular displacement of the field poles of one machine with respect to another must not vary more than approximately ± 3 electrical degrees, or a total of 6 electrical degrees. Since 360 electrical degrees constitute the space between adjacent like poles, the total variation in mechanical degrees, for example, in the case of a 20-pole machine, must not exceed 0.6 degree. While successful operation under such requirements is carried out in several land installations where the prime movers operate at

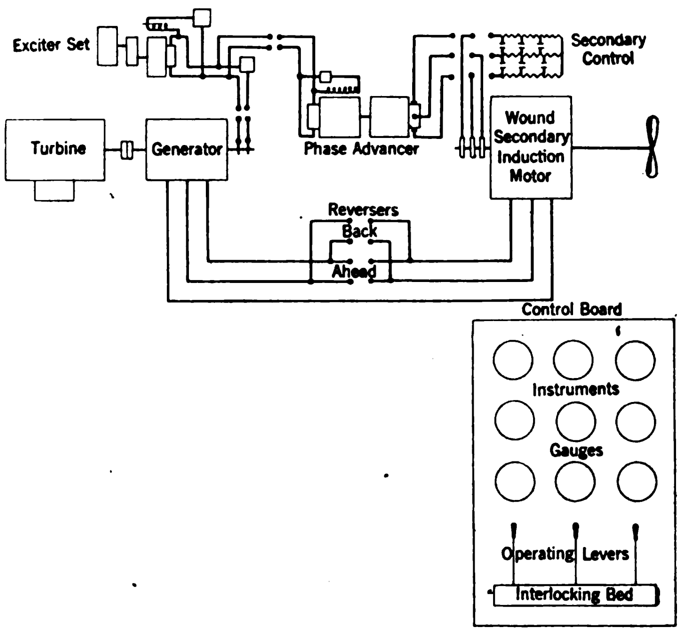

Fig. 4—Wound-Secondary Induction-Motor Drive with Phase Advancer for Power Factor Correction
Diagrammatic scheme of connections.

constant speed, it is not considered safe practise on board ship *where the necessity for varying the speed of all sets simultaneously* introduces another very serious difficulty. To overcome this condition successfully, would require absolutely perfect engine governors which would function 100 per cent perfect at any speed setting. The speed of the motor could be varied by the rheostatic method, thus allowing the engines to operate at constant speed; however, this method is extremely wasteful at reduced speed operation, and at best offers a solution for only one of the many difficulties. It is for these reasons that alternating current is not suitable for Diesel-electric propulsion.

Direct current not only obviates all of the above difficulties, but possesses many advantages in the way of operation, control and reserve power. With direct

current, we have the choice between two methods of generator operation, *i. e.*, parallel and series. From the standpoint of engine performance only, parallel operation of d-c. generators is entirely feasible and easily accomplished. However, when considering economical methods of speed control of the propeller motors, another factor enters which makes parallel operation difficult, even with d-c. machines. This is explained below.

For a drive of any appreciable size, the best results are obtained by isolating the propulsive equipment so that immediate maneuvering can be done without affecting non-related circuits. Therefore, having an isolated plant for propulsion only, voltage control is obviously the method to use.

With parallel operation of generators, voltage control is not simple of accomplishment. To vary satisfactorily the voltage of two or more generators simultaneously over the full range from zero to maximum, necessitates very closely and very carefully adjusted field rheostats, generators with practically identical saturation curves, and engines with practically identical regulation; or, some complicated and delicate automatic voltage balancing instrument.

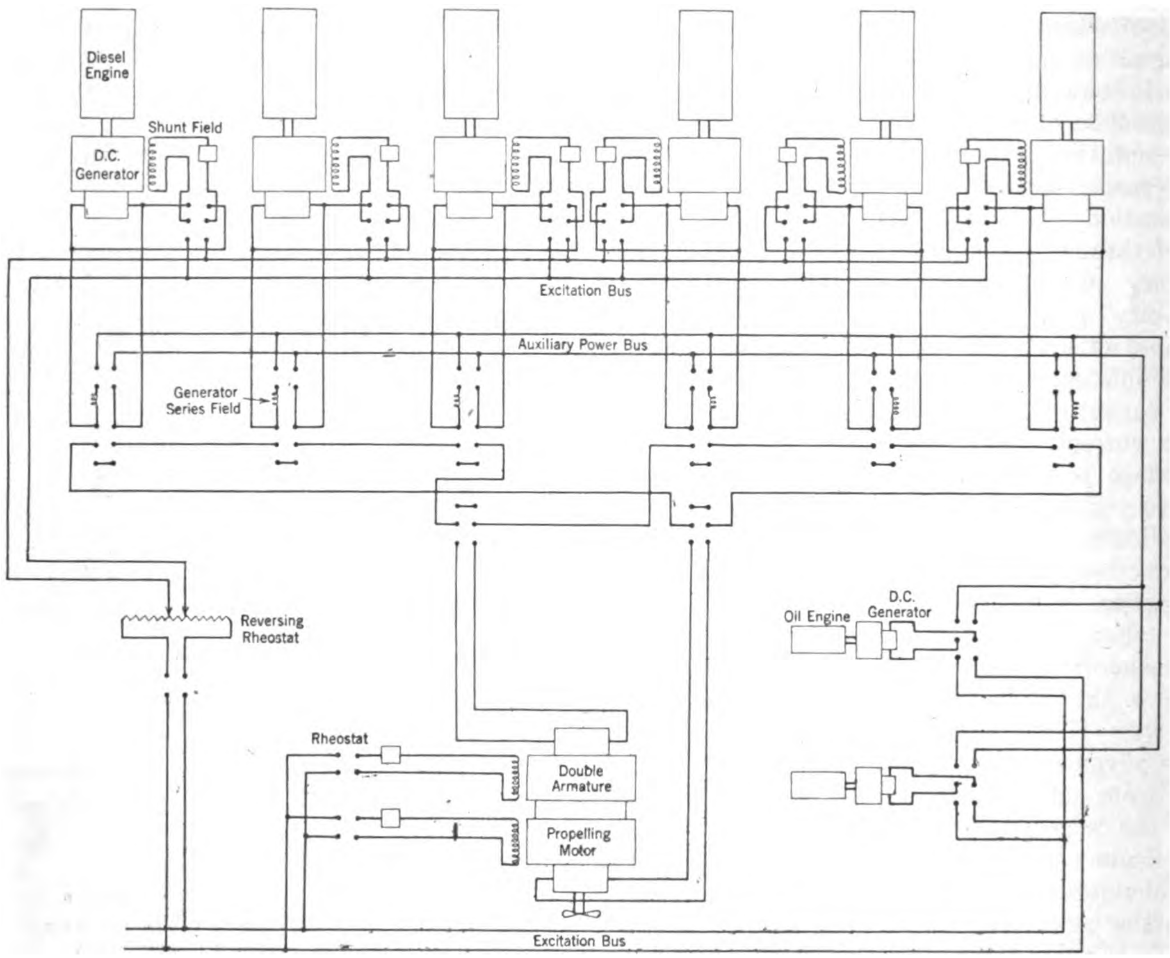

FIG. 5—DIESEL ELECTRIC DRIVE
Diagrammatic scheme of connections.

With direct current, we have a choice between two methods of motor speed control, *i. e.*, armature rheostatic and generator voltage control. Armature control is not only unjustifiably wasteful at reduced speed operation, but also adds complication to the control. On the other hand, the voltage control method is practically 100 per cent economical and provides an ease and a flexibility of control unapproachable by other systems. In the case of very small drives, armature rheostatic control might be selected because of factors not related to the propulsive equipment making it preferable to have a constant voltage system which is common to the propulsion and auxiliary circuits.

The series arrangement of generators, however, is ideal from every standpoint such as operation, control, economy, simplicity, flexibility, reserve, etc. The series arrangement, in eliminating parallel operation of generators, obviates the necessity for close regulation and hence simple engine governors and simple field rheostats are entirely satisfactory. In other words,

satisfactory operation is independent of variation in voltage between the different generators.

Besides the operating advantages, the series arrangement inherently provides for full power from each of the remaining generators in case of casualty to one or more of the generating sets without providing additional capacity, and consequently additional weight in the motor. To obtain full power from each of the remaining sets with parallel operation would necessitate increasing the motor field in order to lower its speed to such a value as would require the total capacity of the remaining units, thus necessitating a larger and heavier motor.

Fig. 5 shows a diagrammatic scheme of connections for a single-screw Diesel-electric drive. In this particular case, there are six generating sets and one double-unit direct-connected motor. The six generators and the two motor units are connected in series. The machines are distributed electrically as follows: three generators, one motor unit, three generators and one motor unit, to reduce the voltage strain, or the maximum voltage to ground at any two points to one-half the total voltage of the system. The voltage of each generator being 250, we have in effect a 1500-volt system with only 750-volt insulation requirements. The advantages of this arrangement are obvious, especially in the case of large capacity drives and where there are several generators involved. The diagram shows an arrangement for using as many as may be desired of the main generating sets for supplying power to the ship's auxiliaries when in port. Although the generators (and motors) operate as pure shunt machines when driving the ship, series windings on the generators are automatically placed in circuit when the generators are connected to the auxiliary bus, and therefore, the generators operate as compound machines when supplying the auxiliary load, and when used for this purpose the generators are operated in parallel. Arranging the generators for supplying power to the ship's auxiliary bus determines the voltage of the individual machines (250 volts).

The motors and generators being pure shunt-wound machines, the motor speed is adjusted to any value within the requirements by the voltage control system. In this system, the generator and motor fields are separately excited (preferably from the same excitation source). The motor fields are excited at constant potential, and in one direction, whereas the generator field excitation is varied to obtain the motor speed desired. With this arrangement, the speed of the motors is directly proportional to the generator voltage and, therefore, any motor speed from zero to the maximum in either direction is obtained by merely manipulating the generator field rheostat (a common rheostat is used for all generators). Since the rheostat handles only the generator field current which is 1 per cent to 1½ per cent of the generator rating, the simplicity and economy of the control is obvious. With the type of rheostat used, the excitation of the generators may be varied from full excitation in one direction to full excitation in the opposite direction, without opening the field circuit, and therefore, the ship can be brought from full speed ahead to full speed astern without opening a single circuit.

Reserve power in the event of casualty to prime movers is greater with this type of drive than with any other. On the basis of the power varying as the cube of the speed, a three-engine unit Diesel-electric ship can make 88 per cent speed with two generators and 70 per cent speed with one generator.

The Diesel-electric has the greatest range of application of any of the economical drives (geared turbine and turbine-electric not excepted). Because of the inherent merits of this drive, it is very suitably applied to merchant ships, barges, river-boats, lake boats, ferry boats, small coast-wise vessels, yachts, fishing boats, coast guard cutters, cable laying ships, and any ship within its capacity requiring refined control and economical operation over a wide range of speed.

As compared with any type of steam drive, the principal advantages of the Diesel-electric are:

Fuel consumption,

Weight,

Control,

Considerably more reserve power in case of casualty to prime movers.

The principal advantages of the Diesel-electric drive as compared with direct Diesel drive are:

Reliability. Cylinder parts being thinner are not subjected to such high temperature strains in heads and liners as are the large low speed engines, and conquently, there will be fewer breakages of these parts. Years of application and service demonstrate beyond a doubt the full reliability of electrical machinery.

Maneuvering Ability and Control. The control is extremely simple, easily understood, and can be placed anywhere on the ship. The engines run at constant speed and hence the engine reversing gear is eliminated.

Weight. On a very conservative basis, the Diesel-electric should show at least 100 pounds less per propeller shaft horse power.

Propeller Application. Propeller speed not restricted, and in the case of large ships, one propeller would be used for Diesel-electric, whereas, because of engine conditions, two would be used with direct Diesel.

Reserve Power in Case of Casualty. Very much greater with the Diesel-electric.

Maintenance. For reasons under "Reliability", the maintenance should be less. Furthermore, due to smaller parts and reserve power, repairs to Diesel-electric engines can usually be made on board ship while under way, providing sea conditions permit. The engines for Diesel-electric are designed and built on the same conservative basis as direct-drive Diesels, and are not the high-speed, short-lived submarine type.

Less Starting Air. Diesel-electric requires starting air only during the initial start in port. Subsequent engines may be started electrically. No air is used during reversing and consequently, the air problem is reduced to simplest terms.

Fuel Consumption. There would be little difference in the net fuel oil and lubricating oil consumption as the increased efficiency of screw and the reduced strutt losses, with the low-speed single-propeller Diesel-electric, offset the twin-screw arrangement of the direct Diesel. From a standpoint of piston speed, the engines used for Diesel-electric drive are no different than direct-connected engines. (The former exceeds the latter only in *revolutions per minute*).

Cost. The cost of Diesel-electric in some cases is less than the cost of direct-connected Diesel drive on present day figures, and will generally show a greater gap when fully developed along standardized lines.

General Summary for Merchant Ship Electric Drives

In the way of a summary relative to all types of electric propulsive equipments for merchant ships, the following salient features may be reviewed:

1. Electric drive is as reliable as any drive suitable for ship propulsion.
2. Maintenance and repairs should not exceed those of other drives, and in some cases should show a saving.
3. Electric drive is ideal for ship propulsion, and will soon be recongized (if it is not already recognized) as a standard type along with the reciprocating engine, geared turbine and Diesel engine drives.
4. Electrical machines have longer life than engines or geared turbines (drives) and do not decrease in efficiency with age.
5. Electric drive (Diesel-electric) is as reliable as any economical drive generally; weighs less than any other drive; is as economical as the best; in most cases costs less than any other drive;* provides more reserve power in case of casualty to prime movers; and affords simplest and most flexible control.

War Vessels

The electric propulsive equipments for war vessels have been described and discussed in many articles in the technical press, and therefore, only the principal phases will be dealt with here.

The fact that the last nineteen capital ships of the U. S. Navy are, or will be equipped with electric drive, is sufficient testimony in behalf of what the builders and users of war vessels think of its merits. The prime requisite of reliability in any type of machinery designed to propel war vessels was recognized in the electrical machinery at the time of the first installation. Also the calculations showed that the unit fuel consumption over a wide range of operating speeds should be better than anything yet proposed. Service operation of two 30,000-h. p. electrically propelled battleships has indisputably proved that the reliability is all tath was claimed, and that the fuel economy as compared with other ships of the same type using direct-connected turbines with geared cruising turbines, is vastly superior.

*It is predicted that future developments will bring the item of cost below that of any other drive.

Two other factors in which the electric drive shows a marked improvement over other drives, have been emphasized since the first battleship was built, namely, the superior protection from torpedo attack afforded the machinery by virtue of the arrangement of the electric plant, and the superior maneuvering qualities of the electric drive. The large horse power requirements of the present war vessels (60,000 h. p. and 180,000 h. p.) preclude the use of reciprocating engine drive, and this leaves electric drive with a decided maneuvering advantage over any other form of turbine drive.

Of the two types of electric propulsive equipments, only the turbine-electric is suitable for propelling war vessels, because of the large capacities required. The nineteen drives installed and building employ essentially the same system in that induction motors are used in all cases. In details, the systems differ in regard to the type of induction motor. Of the three ships in service, (the *Maryland* having been recently commissioned), the *New Mexico* motors have the double squirrel-cage rotor winding, the *Tennessee* motors have the form-wound rotor with external starting and maneuvering resistance, and the *Maryland* motors have combined single squirrel-cage and form-wound rotors. Each of these arrangements has its advocates. However, continued service alone will decide which method is the most suitable, all factors being considered.

Because of limitations in weight and space factors, electric drive is not well suited to small, high-power, fast craft such as destroyers and scout cruisers. In the case of ships where conditions are suitable for electric drive, the following dicussion of the more important factors will be of interest:

Reliability

In all phases of the industrial field where electricity has entered, it has proved its reliability. With a good record for reliability behind it, electricity has set out to establish a similar record on the sea, and the experience of the two large battleships thus far equipped with electric propelling machinery, and in service, shows that there will be a duplication of past satisfactory performance. The electrical machinery will be found to be in good condition long after the ship has become obsolete.

The arrangement of units and distribution of power make it possible to supply balanced power to all screws in the event of casualty to one of the prime

movers. In other words, the electric drive possesses an inherent advantage in regard to reserve power.

Economy

Regardless of calculations, the recorded performance of the electrically propelled battleship *New Mexico* has proved the superiority of the electric battleship in respect to fuel consumption. Recently published figures in the *Marine Review* show that the *Idaho* and *Mississippi* use 20 per cent more oil at 10 knots than the *New Mexico*; 42.7 per cent more at 13 knots, 48 per cent more at 16 knots, 40.1 per cent more at 19 knots, and 32 per cent more at full power. This superiority in fuel consumption is not altogether due to the main units, as the figures include the oil consumed by the auxiliaries. There is enough difference, however, to show conclusively that the comparison is very favorable to the electric ship.

To show that the advantage in fuel consumption demonstrated by the *New Mexico* is not a mere incident, it is well to note that the *Tennessee*, which is a later ship, is showing even better results than the *New Mexico*, as was indicated when the two ships steamed together during recent maneuvers of the Pacific Fleet. Accurate measurement of unit fuel consumption during the official trials of the *Tennessee* showed that the actual steam consumptions were less than the guaranteed figures by amounts varying from 3 per cent to 8 per cent approximately. Thus the art of electric propulsion is still progressing. The answer is found in the use of only a sufficient number of turbines for the load conditions, and in the two-speed motors, the combination of which maintains a higher average load on the turbines at a higher average speed.

ELECTRICALLY PROPELLED WAR VESSELS IN SERVICE AND BUILDING.

Ship	Kind	Total S. H. P.	Type of drive	Tonnage	Date
U. S. S. Jupiter	Collier	7,000	Turbine-electric	20,000	1912
" New Mexico	Battleship	28,000	" "	33,000	1918
" Tennessee	"	28,000	" "	"	1920
" Maryland	"	28,000	" "	"	1921
" California	"	28,000	" "	"	Building
" Colorado	"	28,000	" "	"	"
" Washington	"	28,000	" "	"	"
" West Virginia	"	28,000	" "	"	"
" South Dakota	"	60,000	" "	43,000	"
" Indiana	"	60,000	" "	"	"
" Montana	"	60,000	" "	"	"
" North Carolina	"	60,000	" "	"	"
" Iowa	"	60,000	" "	"	"
" Massachusetts	"	60,000	" "	"	"
" Lexington	Battle Cruiser	180,000	" "	43,500	"
" Constellation	" "	180,000	" "	"	"
" Saratoga	" "	180,000	" "	"	"
" Ranger	" "	180,000	" "	"	"
" Constitution	" "	180,000	" "	"	"
" United States	" "	180,000	" "	"	"
Japanese Fuel Ship	Collier	8,000	" "	20,000	"
4 Coast Guard Cutters	Cutter	2,600	" "	1,600	"

ELECTRICALLY PROPELLED MERCHANT & MISCELLANEOUS SHIPS IN SERVICE AND BUILDING.

Ship	Kind	Total S. H. P.	Type of drive	Tonnage displaced	Date
2 Ice Breakers at Niagara Falls	Tug	50	Trolley or cable fed, d-c.		1906
Joseph Medill	Fire boat	400	Turbine-electric d-c.		1908
Graeme Stewart	" "	400	" " "		1908
Electric Arc	Experimental Launch	25	Petrol-electric a-c.		1911
Tynemount	Cargo	500	Diesel-electric a-c.		1912
Mjolner	Cargo	950	Turbine-electric a-c.		1912
Wulsty Castle	Cargo	1,500	" " "		1918
Aquila, etc	Cargo	1,200	" " "		1918-9
Mariner	Trawler	400	Diesel-electric d-c.	500	1919
Eclipse	Cargo	3,000	Turbine-electric a-c.	16,000	1920
Cuba	Cargo & Passenger	3,000	" " a-c.	3,580	1920
Elfay	Schooner Yacht	90	Diesel-electric d-c.	313	1920
Guinevere	" "	550	" " d-c.	1,160	1921
Invincible	Cargo	3,000	Turbine—electric a-c.		Building
Archer	"	3,000	" " "		"
Independence	"	3,000	" " "		"
Alcyone	Schooner Yacht	350	Diesel-electric d-c.		"
Velero II	" "	215	" " "		"
Fordonian	Cargo	850	" " "	2,200	"
8 Cargo Carriers		3,000	Turbine-electric a-c.	16,000	"
Poughkeepsie-Highland Ferry	Ferry	200	Diesel-electric d-c.	640 DWC	"

Maneuvering

Owing to the availability of full backing power in the case of the electric drive ship, the latter possesses

a marked advantage over the turbine ship in maneuvering qualities. As these were referred to under "Merchant Ships," it is sufficient merely to mention at this time that electric battleships can be stopped in considerably less time than is required to stop a turbine ship. The advantage of this feature is obvious in the case of a war vessel. This is due to the combined action of quicker "set-ups" and greater backing power.

Further maneuvering advantages of the electric drive are apparent from recent publications. These advantages are chiefly concerned when entering and leaving ports and maneuvering therein. By operating the ship from one turbine set, the other, or others if there are more than two, can be held in readiness for immediate service in case of necessity such as would arise from a mudded condenser or other cause. When maneuvering to get under way, operation from a single generating set inherently enables exactly the same speed—but of opposite direction—to be obtained on the port and starboard screws. This is very desirable for the reason that the ship can be turned on its heel without making any headway. With different prime movers supplying power to the various screws, it would be difficult to maintain all the screws at the same speed and thereby turn in the same space.

Control

The control for the propelling machinery is centralized in one compartment and can be easily arranged to be operated by one operator. The flexibility of the control is such that almost any emergency resulting from casualty to any equipment connected with the propulsive machinery proper, can be taken care of in brief time by disconnecting the disabled unit from the source of power.

Maintenance

The maintenance and repairs should show to advantage because of the inherent reliability of electrical machines and the absence of wearing parts. Repairs of considerable magnitude can be made aboard the ship without removing the machinery. It is difficult to imagine a casualty to any one of the electrical units which could not be repaired on board the ship if circumstances warranted it.

Study of Performance

The electrical instruments enable accurate and convenient observations to be made of the performance of the screws at any instant. The electrical instruments also provide a means for quickly detecting improper performance of the screws due to excessive shaft friction or damaged blades. The performance of all units as indicated by the instruments is under the observation of the watch officer and control-room attendants at all times.

TELEGRAPH AND TELEPHONE NOTES

The committee on Technical Training, Telegraph and Telephone Section, American Railway Association, is planning organized instruction for communication department employees. The committee also has in view cooperation with established engineering schools looking to improvement in the character of instruction given students who aim to enter communication service.

Brigadier General Edgar Russel, chief signal officer, 2nd Corps Area, New York, will spend several months at Camp Knox near Louisville, Ky., on official duty.

The research department of the Radio Corporation of America, under the direction of Dr. A. N. Goldsmith, has recently made important improvements in tape recording receiving systems for transatlantic radio signaling.

The Morris Liebmann Memorial Prize, for the year 1921, has been awarded to Raymond A. Heising, of the Western Electric Company, New York, for his analysis of vacuum tube action and his research work on modulation systems. The prize is awarded by the Institute of Radio Engineers.

The wide extension of radio broadcasting service from a number of centers throughout the country, by means of which news items and musical concerts are given by radio telephony, has created a large demand for radio receiving equipment.

The Telegraphy and Telephony Committee of the Institute held a meeting at Institute headquarters recently at which a tentative program was made up of papers to be presented or published during the coming year. It is likely that the committee will be assigned a place on the program of the Midwinter Convention for the presentation of papers on communication engineering. Subjects of papers now being prepared, and subjects proposed, are:

Submarine Cable Telegraphy.

Key West-Havana Telegraph and Telephone Cable.

Solution of Problems Relating to Suspended Wires and Cables.

Relation of Track Signaling and Communication Engineering.

The Engineering Features of Telegraph Traffic Handling.

Engineering Features of Radio Broadcasting.

Shielding Effect and Wind Pressure Observed on a Ten-Wire Experimental Telegraph Line at Elizabethport, N. J.

Installation of an Automatic Telephone Exchange in New York City.

Printing Telegraph Systems in Use on American Lines.

A Frequency-Bridge

An Apparatus for Accurate Determination of Frequency, by Means of a Null Method

BY EDY VELANDER

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As long as there was not available in the labaratory any convenient source of alternating current of a satisfactory steadiness and purity, the technique of measurements had to confine itself to such alternating-current bridge-methods where the balance is independent of frequency, so that accidental changes in frequency do not seriously affect the setting, and a reasonable amount of harmonics does not prevent an accurate adjustment. The steadiness and purity of the output from a properly adjusted triode oscillator, however, makes it possible, in a modern laboratory, to take up and successfully apply many convenient methods of measurement, which although known since many years, have been discarded and forgotten for reasons suggested above. On the other hand it enables us to utilize new methods, where the frequency enters explicitly into the result.

It then becomes necessary, however, to provide means for rapid and precise determination of the frequency employed, respectively for the accurate adjustment of this frequency to a predetermined value. With these points in mind the writer undertook to work out a zero-method for measuring frequency, and developed an arrangement which may be called a frequency-bridge.[1] This frequency-bridge has since been extensively used, and while it is particularly suitable as standard for frequency measurements in the audio range, it has also been successfully used for measuring frequencies of the order of 60 cycles.

Strictly speaking, any alternating-current bridge arrangement, where the balance is in any way affected by the frequency of the applied current, could be conversely used as a frequency-bridge. Of all possible arrangements, however, those will give the highest sensitivity, where the balance is based upon a comparison of the voltage across a condenser with the drop across an inductance, or with the induced e. m. f. in the secondary of a mutual inductor. A condensive and an inductive drop will be affected by a change in frequency in just opposite ways, and the balance will therefore be doubly sensitive.

The Campbell Mutual-Inductance-Condenser Method

A method, based upon these principles, was suggested by G. A. Campbell[2], who later[3] proposed certain modifications of the same. In the original Campbell arrangement, a condenser C is connected in series with the primary of a mutual inductance standard M, in the way Fig. 1 indicates, the drop across the condenser C being compared with the mutual reactance drop in the secondary coil by means of a zero-indicator T, for instance a pair of head-phones, or a vibration galvanometer. If I is the primary current, we get, by equating to zero the total drop along the indicator-mesh, and assuming that no current flows in T, the following complex equation for a balance:

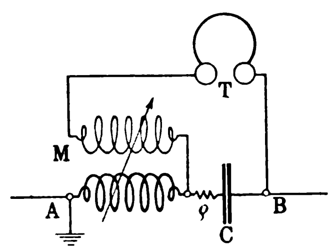

Fig. 1—The Campbell Mutual-Inductance Condenser Method for Measuring Frequency

$$I \,.\, j\,\omega M + I\left(\rho + \frac{1}{j\,\omega C}\right) = 0$$

This is equivalent to two actual conditions of balance:

$$\begin{cases} \omega = \dfrac{1}{\sqrt{MC}} \\ \rho = 0 \end{cases}$$

Since ρ here denotes the equivalent series resistance of the condenser, the last equation indicates that a "perfect" condenser should be used in order to get a clean balance. A condenser of unusually small losses therefore is necessary for refined work, unless some special scheme is used for advancing the phase of the mutual-inductance drop in the secondary.[3] Another difficulty is that the method calls for a con-

1. The frequency-bridge has been briefly described, in a paper on "Rectangular-Component, Two-Dimensional Alternating-Current Potentiometer" by A. E. Kennelly and Edy Velander, *Journal Franklin Institute*, July, 1919, also *Bulletin No. 18*, of the Electrical Engineering Research Division, of the Massachusetts Institute of Technology.

2. G. A. Campbell, *Philosophical Magazine*, 15, 1908, p. 166, and *Proceedings of the Physical Society*, 21, 1908, p. 80.

3. G. A. Campbell, *Electrician*, 80, 1918, pp. 666-667, also *Proceedings of the Physical Society*, 29, 1917, pp. 345-353.

denser and a mutual inductance of such demensions that $M\,C$ is equal to the inverse of ω^2. In measuring low frequencies the product of M in henrys and C in microfarads therefore must be rather large, at 60 ~ about 7, necessitating the use of very large coils, and a condenser of rather high capacity. We understand, however, that the method has been used with much success by Dr. Campbell for accurate calibration of frequency meters in the commercial frequency range.

The Compensated Frequency-Bridge

It was found that by certain modifications of this mutual-inductance-capacity arrangement, it is possible to eliminate both the mentioned disadvantages without introducing too much complication. Several different schemes for this purpose were tried out, and finally the arrangement shown in Fig. 2 was selected as the apparently most satisfactory.

The series-arrangement here is shunted by a resistance R of a few thousand ohms, and the drop across the nth part of this resistance is compared to the mutual-reactance drop in the secondary coil. A small inductance l must be inserted in series with the resistance R, as will be presently seen.

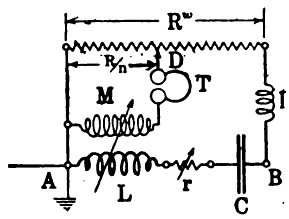

Fig. 2—The New Form of Frequency Bridge

Now, if we assume that no current flows in the indicator T, and if we let V_{AB} denote the voltage across the entire arrangement, then the drop from A to the tap D will be

$$V_{AB} \times \frac{\dfrac{R}{n}}{R + j\,\omega\,l}.$$

The current in the condenser branch is

$$I_C = \frac{V_{AB}}{r + j\,\omega\,L + \dfrac{1}{j\,\omega\,C}}.$$

In r is included the primary coil resistance and also the equivalent series resistance of the condenser. L is the primary inductance. The induced electromotive force in the secondary will be $-j\,\omega\,M\,I_C$, and we get as a condition for balance:

$$V_{AB} \times \frac{\dfrac{R}{n}}{R + j\,\omega\,l} - V_{AB} \times \frac{j\,\omega\,M}{r + j\,\omega\,L + \dfrac{1}{j\,\omega\,C}} = 0.$$

This equation may be broken up into the following two expressions, corresponding to real and imaginary parts:

$$\begin{cases} \omega = \dfrac{1}{\sqrt{C\,(L + n\,M)}} \\ l = R\,r\,C\left(1 + \dfrac{L}{n\,M}\right) \end{cases}$$

The formula for the frequency thus is very simple and easy to remember due to its analogy with the expression for the resonant frequency in a condenser-inductor circuit. The effect of the potentiometer arrangement of R evidently is to multiply the effect of the mutual inductance in the ratio n to 1. If n is chosen reasonably large, say about 20, a balance may therefore be obtained with coils and condensers of reasonable dimensions, even if the frequency to be measured is rather low.

The second equation shows that the small inductance l is necessary for a clean balance. It serves to retard the phase of the current in R the same amount as the current in the condenser is retarded behind the 90-deg. leading position by the resistance r in the main branch. In any practical case the necessary amount of inductance is very small, and it will be found that the adjustment corresponding to the last equation really has the nature of a balance refinement. The bridge therefore will work satisfactorily even if the last condition is only roughly adjusted for.

The Frequency-Bridge in Practise

In practise there are several ways of obtaining a frequency balance with this arrangement. Usually it is most convenient to employ a condenser of a fixed value, and to vary the value of M, or the ratio n. A Campbell mutual inductometer is very convenient as a variable mutual-inductance standard, but for less precise work an ordinary variometer may be used. If such a continuously variable mutual inductor is available, one fixed ratio n is sufficient. A non-adjusted ratio box may easily be made up for the purpose, and the ratio accurately determined with direct current. Since a certain amount of inductance is always introduced in series with the resistance R, it is obvious that at least the bigger one of the ratio resistances need not be non-inductively wound. In fact, it is easy to show, that a reasonable amount of inductance even in the smaller ratio resistance has no detrimental effect upon the accuracy of the bridge.

If no variable mutual inductor is available, a pair of coils with a fixed value of mutual inductance may be used. In this case the variation should be made in the bigger ratio arm, which then conveniently is made up of a decade resistance box of sufficiently fine steps.

If a wide range of frequencies must be covered, it is advisable to provide at least two steps in the condenser. A good method is to have two equal condensers which

may be connected in parallel or in series. The calibration of the instrument then will be altered exactly in the ratio 1 to 2, since the capacity when changing the condenser connections is altered in the ratio 4 to 1.

The condensers need not be very accurately adjusted. Assume, for instance, that their capacities are c_1 and c_2 and let us denote their arithmetical mean by c_0. We may then write

$$\begin{cases} c_1 = c_0\,(1+\epsilon) \\ c_2 = c_0\,(1-\epsilon) \end{cases}$$

For parallel connection the capacity evidently will be $C_p = 2\,c_0$, and for the series case we obtain:

$$C_s = \frac{c_0\,(1+\epsilon) \times c_0\,(1-\epsilon)}{c_0\,(1+\epsilon) + c_0\,(1-\epsilon)}$$

or

$$C_s = 1/2\,c_0\,(1-\epsilon^2)\ .$$

The ratio of C_p to C_s then will be

$$\frac{C_p}{C_s} = 4\,(1-\epsilon^2)$$

and thus

$$\frac{f_s}{f_p} = 2\,(1 - 1/2\,\epsilon^2)\ .$$

Hence, if the relative deviation in capacity between the two condensers, or $2\,\epsilon$, is as much as 2 per cent, the error in assuming that the calibration changes exactly in the ratio 2:1 will be only five parts in one hundred thousand, a quantity which for ordinary work is entirely negligible. Even if the capacities are as 9 to 11, the error is only one-half of a per cent.

The auxiliary adjustment in l, corresponding to the equation

$$l = R\,r\,C\left(1 + \frac{L}{n\,M}\right)$$

is most easily obtained by winding up a small coil of fixed inductance of a little bigger value than required, while a fine-adjustment is made on a small resistance in series with the primary coil L. This resistance should have rather fine steps, but need not be calibrated. It should have a maximum value approximately equal to the resistance of the primary. The resistance of the small auxiliary coil l must of course be accounted for in determining the ratio n.

In order to secure a high sensitivity the balance indicator should have an impedance of the same order as the impedance of the secondary of the mutual inductor plus the smaller ratio resistance R/n. An ordinary low-impedance vibration galvanometer therefore gives very good sensitivity with the described bridge. The most convenient balance indicator, however, is a pair of telephones, but for good sensitivity a pair of low-impedance receivers should be selected, and the mutual inductor should be wound with many turns on the secondary and few on the primary. (This has the additional advantage of giving a low value of r, and thus reducing the importance of the auxiliary adjustment in l.) A fairly good sensitivity sometimes may be obtained also with receivers of high resistance, if a good step-up telephone transformer of suitable ratio of transformation is interposed.

A Wide-Range Frequency-Bridge

A convenient form of long-range frequency-bridge, embracing the entire telephonic frequency range, is shown in Fig. 3. An alternating current of a few milliamperes of the frequency to be measured is passed through the bridge from A to B. It is desirable to ground the point A so as to avoid disturbances from spurious capacity currents. C is the standard condenser, made up of two clamped mica units, adjusted within per cent to a capacity of 0.4 microfarad. These units may be connected either in series, by plugging as indicated by full dots, or in parallel as shown by small circles. The working capacity thus is either 0.2 or 0.8 microfarad.

L is the primary coil, with a small auxiliary fine-step resistance σ in series. The secondary coil M is shown to have three fixed subdivisions, $a-b$, $b-c$, and $c-d$. Each is adjusted to about 2.5 millihenrys mutual inductance, and one, two, or all three of them may be connected in series by turning the handle I. A rotating, fine-adjustment coil is provided, which gives a continuous variation from 0 to 2.5 millihenrys. By dividing the fine-adjustment coil into two equal subdivisions, one fixed, and one rotating, the scale from 0 to 2.5 millihenrys may be made to embrace a 180-deg. angle thus permitting a very accurate setting. The rotating part of the fine-adjustment coil is manipulated by the handle II.

The smaller ratio resistance, which corresponds to R/n above, is kept fixed at 100 ohms, but the value of R may be set at 500, 2000, or 8000 ohms by turning the selector switch III. This gives three values of n, namely 5, 20, and 80, which stand to each other in the ratio 1:4:16, corresponding to changes in frequency range approximately as 1:2:4.

As shown by the formula above, l is, for a constant value r, approximately proportional to the product $R\,C$ (since $\frac{L}{n\,M}$ is a small quantity in comparison to unity). Thus four values of l must be provided, corresponding to the four possible values of $R\,C$ which range from $500 \times 0.5 \times 10^{-6}$ to $8000 \times 0.8 \times 10^{-6}$. This is accounted for by four taps on the coil l, roughly adjusted to give inductance values corresponding to these four values of $R\,C$. The total resistance introduced by the auxiliary coil is for each tap adjusted to a certain convenient value, say ρ ohms, and to compensate for this increase in resistance in the R-branch, the second unit in this branch, which should have had the resistance 400 ohms, if the coil l had had no resistance, is instead adjusted to $400 - \rho$ ohms.

The selector-switch III automatically picks out the right tap on l when the desired R-value is connected. However, since there are two possible values of capacity for each step in R, a double-point system must be used, as shown in the figure, allowing for the six possible combinations of R, C and l.

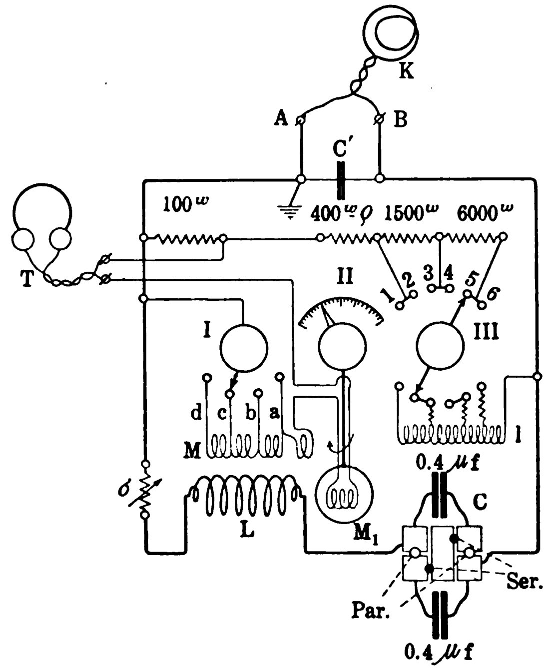

FIG. 3—COMPLETE WIRING DIAGRAM OF A LONG-RANGE FREQUENCY BRIDGE

With a variation of M from approximately 2.5 millihenrys to 10 millihenrys, we obtain with this bridge the following frequency-ranges:

Position of Switch III.	R ohms	Condenser:	n M C $m\,h\,.\times\mu f$	Frequency
1	500	series	2.5—10	3200—1600
2	500	parallel	10—40	1600— 800
3	2000	series	10—40	1600— 800
4	2000	parallel	40—160	800— 400
5	8000	series	40—160	800— 400
6	8000	parallel	160—640	400— 200

As seen from the table, there are in the middle of the working range two possible settings for the measurement of each frequency value. Usually one or the other will give a clearer balance. If it should so happen, that the condenser arm, at the frequency to be measured, gives resonance with the supply coil for one of the harmonics in the supply voltage, this harmonic will be accentuated, and disturb the balance. By changing the condenser setting, however, the undesirable harmonic usually may be cut down to normal size. The bridge naturally is rather sensitive to impurities in the wave form, and sometimes, when a telephone is used as an indicator, it is necessary to employ some filtering arrangement, either on the supply side, or in the telephone leads, or both. The condenser C, on Fig. 3, of a few tenths of a microfarad capacity, represents a rudimentary electric filter, and often improves the balance materially by serving as a by-pass for overtones. Sometimes it is better to insert a variable condenser instead of C and tune up the supply circuit, with the coupling coil K, to resonance for the fundamental. A simple filtering scheme which has proved rather useful at frequencies in the neighborhood of 1000 ~ is shown in Fig. 4. The coils used were ordinary iron-cored telephonic loading coils. The difficulty in designing a filter for a long-range frequency-bridge naturally is the necessity of making the cut-off point of the filter adjustable.

The entire frequency-bridge, as shown in Fig. 3, may be built into a box, if proper care is taken to avoid mutual inductance between the main mutual inductor and the compensating device l. The instrument then becomes a portable, completely self-contained unit, with only four binding-posts, two for the supply, and two for connecting the indicator, telephones or vibration galvanometer, as the case may be. If the steps b, c, d are omitted, the movable coil may be graduated directly in frequency. It then is advisable to use a somewhat larger fixed secondary coil in series with the rotating coil, so that the full range of 180 deg. on the latter will correspond to a mutual inductance change in the ratio of 1 to 4. By placing the coils so as to give a proper distortion of the mutual-inductance calibration, a reasonably even frequency scale may be obtained. With a series-parallel connected pair of condensers a frequency-range of, say, 500-2000 ~ thus may be covered on one double-reading scale of 180 deg. angle.

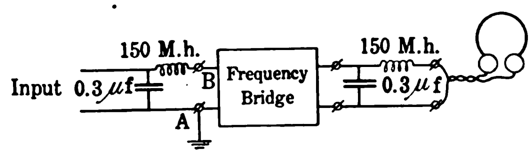

FIG. 4—FILTERING ARRANGEMENT USED WITH THE FREQUENCY BRIDGE

The frequency-bridge as described above gives a remarkably good accuracy of setting. With only a few milliamperes through the bridge, and a pair of good telephones, frequencies in the audio range may easily be determined to within a fraction of a cycle, if the mutual inductor has a sufficiently fine graduation. Below 500 ~ the telephone sensitivity rapidly decreases, and a vibration galvanometer is superior.

It must be noted, however, that in this bridge, as in any other alternating-current null-method, the balance is very sensitive to stray fields, whether inducing in the secondary directly, or in the telephones themselves. In accurate work, therefore astatic coils should be used, and the telephones kept at a considerable distance from the mutual inductor.

Extension to Higher and Lower Frequencies

The bridge appears to be useful also in work at frequencies above the telephonic range. Although, at a high frequency, it is easy to fulfil the requirement $M C = 1/\omega^2$ of the simpler Campbell method, the distributed capacity of the coils used, sometimes causes difficulties, especially as in this method, the common point of the two coils in the mutual inductor must not be grounded, if correct results are required but instead the point A or B, Fig. 1, must be grounded. In the frequency-bridge here described, these inconveniences are partly eliminated, since smaller coils may be used, and disturbances due to capacity to ground may be avoided by grounding the bridge at A, Fig. 2, and Fig. 3.

In work at higher frequencies the secondary circuit should be tuned with a condenser, and a crystal- or tube-detector with a d-c. galvanometer used as a balance indicator.

In connection with some work with the rectangular potentiometer,[1] the author has used the bridge for the direct determination of frequencies in the commercial frequency range, as far down as 50 $\sim$ and lower. A triode oscillator was used as a source of supply, and the indicator was a Campbell vibration galvanometer. The constants of the bridge during these experiments were as follows: $C = 1\,\mu$ f., M = 50-100 mh., R = 8000 ohms, n = 80, l = 300 mh. (This unusually high value of l was partly accounted for by the rather large primary resistance of the 400-millihenry variometer used as a mutual inductor.)

With this arrangement it was easy to adjust the frequency to within 1 part in 5000 of a given value.

NOTES FROM THE BUREAU OF STANDARDS

Standard Radio Wavemeter

The Radio Section of the Bureau is called on to test for government agencies, commercial and university laboratories, and others a great variety of radio material, especially wavemeters. Not only in connection with radio communication, but also in a wide and growing field of electrical research, there is an insistent demand for accurate measurement of the wave length or frequency of rapidly alternating currents. In the standard wavemeter most recently designed by the Bureau, careful attention has been given to the electrical and mechanical considerations which make for accuracy, especially rigidity of construction, and precision of set and reading. This wavemeter, when calibrated, will be capable of measuring wave lengths from 65 to 85,000 meters, or in terms of frequency from 3500 to 4,600,000 cycles per second.

A typewritten description of this wavemeter has been prepared and is available for distribution to interested persons.

Standard Specifications for Large Incandescent Electric Lamps

For about 14 years electric lamps have been purchased by the federal government under specifications published in Circular 13 of the Bureau of Standards. Progress in the art of lamp manufacture has been so rapid that this circular has had to be revised eight times in order to keep the specifications abreast with current developments.

The 9th edition of this circular has just now been published and may be obtained at five cents per copy from the Superintendent of Documents, Government Printing Office, Washington, D. C. The original specifications covered only carbon filament lamps while in the later editions metallized carbon and tantalum lamps were introduced and then discarded as tungsten replaced them in use. In connection with these radical changes in types of lamps, very great improvements were made in the efficiency and the life required, but no fundamental change was made in the form of the specifications or methods of testing. However, for the fiscal year beginning July 1, 1921, new specifications have been adopted which include important changes in the test procedure for tungsten lamps. The most notable of these changes is the abandonment of the long-established provision that the life of test lamps shall be considered as ended when the candle power has fallen to 80 per cent of the initial value. Now the life is considered as the total life of the lamp since the efficiency of tungsten lamps drops but very little up to the point of burn-out. The performance of a lamp throughout its life will also be taken into account and tolerances are provided to care for possible variations in test results where only a small number of samples of any one order are available.

Tests under these new specifications are intended to give a more complete indication of the performance of lamps than was the case with the former specifications and while prepared primarily for use by the departments of the government in purchasing incandescent lamps, it seems desirable on account of the thoroughness with which the subject has been studied and discussed to make the specifications available for the general public. It is for this reason that they are being used as the 9th edition of Circular 13.

Criticisms and suggestions concerning these specifications and lamp ratings are invited from both manufacturers and users and all such suggestions will be carefully considered in the event of a further revision of the specifications.

Abnormal Voltage on Y-Delta Transformer Bank Due to Reversed Connection

BY C. R. REID

Shawinigan Water and Power Co.

THE writer recently observed some abnormal voltage conditions on a Y-delta connected transformer bank which suggested the subsequent investigations described in this paper. The transformers were rated at 50 kw., 30 cycles, 12,000/2300 volts, and were Y-connected to a 22,000-volt, 62½-cycle line. This line was fed by a bank of 50,000/13,200 volt, transformers Y-connected on the low tension side, and with grounded neutral as shown in Fig. 1.

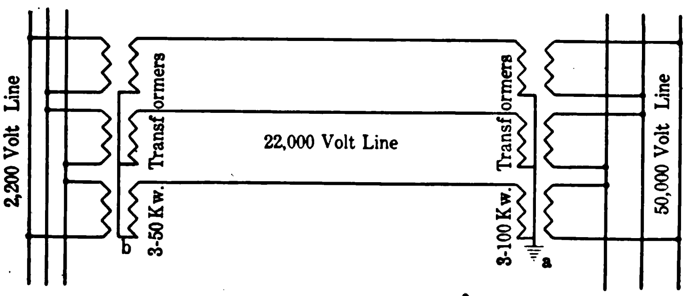

FIG. 1

Since the spare transformer was of the same type as the one it replaced, no effort was made to check its polarity before it was put into service. When the high-tension switch was closed and power put on the bank, the transformer newly connected gave out a loud humming noise and a check of the voltage on its low-tension side showed it to be something like 300 per cent of normal. A check on the connections

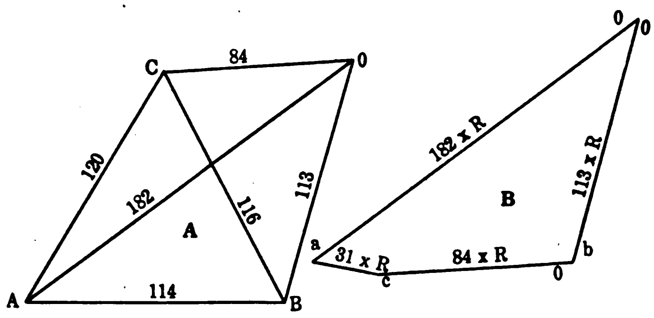

FIG. 2—BANK OF 15-WATT POTENTIAL TRANSFORMERS
A—Diagram of *Y* voltages
B—Diagram of delta voltages

showed that the transformer had been connected in with reversed polarity. When the proper connections were made, the transformer went into service without further trouble. It should be borne in mind that these were 30-cycle transformers operating on 62½ cycles. For this reason the excessive voltage did not cause undue distress.

Later on, a bank of three 6000/100-volt, 15-watt, 25-cycle potential transformers was set up in the laboratory, the 6000-volt windings were delta connected and the 100 volt windings were Y-connected, with one phase reversed, to a three-phase, 62½-cycle, 110-volt circuit. Voltage readings were taken on the low-tension side between phases and between phase wires and neutral. The following readings were obtained; *A*, *B* and *C* denoting the phase wires and *O* denoting the neutral:

A B	*B C*	*C A*	*A O*	*B O*	*C O*
114	116	120	180	115	86

A diagram of voltages was laid off as shown in Fig. 2. The phase voltages were first drawn to form the triangle *A B C* and then arcs were struck from *A*, *B*, and *C* with radii *A O*, *B O*, and *C O* corresponding to the measured values of voltage. These three arcs did not exactly meet in a point, but *O* was located at the center of the triangle formed by their intersections and the voltages *A O*, *B O*, and *C O* corrected accordingly. A triangle of secondary voltages was

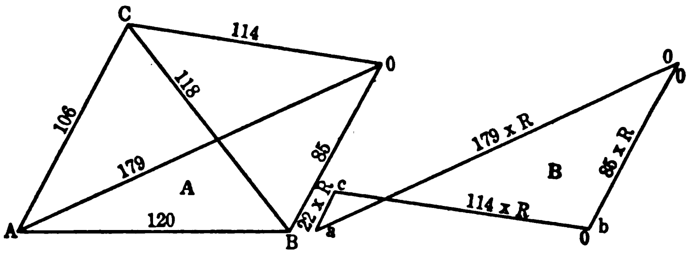

FIG. 3—BANK OF 15-WATT POTENTIAL TRANSFORMERS
A—Diagram of *Y* voltages
B—Diagram of delta voltages

laid out as shown at *B* in Fig. 2. This triangle did not close by 31 *X R* volts, indicating a circulating current in the delta. An ammeter connected in the delta showed a circulating current of 0.19 ampere.

Two of the 110-volt supply leads were reversed in order to change the phase rotation. Readings were then taken as follows:

A B	*B C*	*C A*	*A O*	*B O*	*C O*
120	118	106	178	86	115

From these readings a voltage diagram, (Fig. 3) was made up. By an inspection of Figs. 2 and 3 it is apparent that the phase rotation was responsible for the displacement of the neutral point *O* to one side of the axis of symmetry of the diagram.

In order to decrease errors due to high reactance a test was made on a bank of 5000-kw., 60-cycle, 6600/57,800-volt transformers. This bank was delta connected on the low-tension side and Y-connected on the high-tension side with the polarity of one trans-

former reversed. A 200-volt, 62½-cycle, three-phase circuit was connected to the high-tension winding and the following readings obtained:

AB	*BC*	*CA*	*AO*	*BO*	*CO*
190	190	190	320	180	180

A diagram was constructed from these voltages, (Fig. 4). This diagram shows that there was no displacement of the neutral point due to phase rotation. In fact, a set of readings taken with opposite phase rotation gave identical results. The resultant voltage in the delta was 13 *X R* volts and consequently the current circulating in the delta must have been quite small, though no attempt was made to measure it.

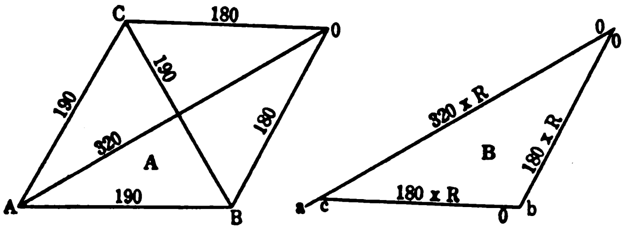

FIG. 4—BANK OF 5000-KW. TRANSFORMERS
A—Diagram of *Y* voltages
B—Diagram of delta voltages

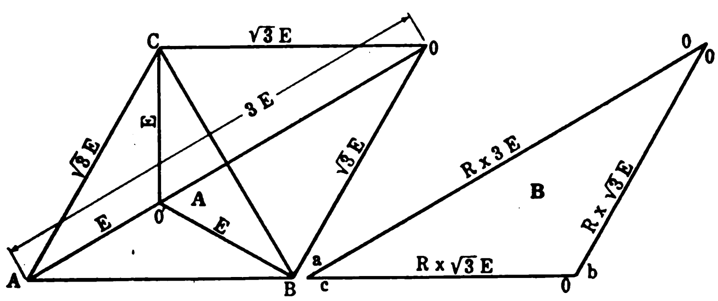

FIG. 5—THEORETICAL VOLTAGE RELATIONSHIPS
A—Diagram of *Y* voltages
B—Diagram of delta voltages

Fig. 5 is a diagram of the theoretical voltage relationships for the primary and secondary. This diagram fulfills the conditions that the three primary voltages to neutral when plotted should meet in a point; and that the three secondary voltages, (which must of course be plotted parallel to and proportional to the primary voltages), should form a closed triangle, *i. e.*, have no resultant voltage. These conditions will be modified in actual practise by the differences in the characteristics of the transformers, and also by the excessive magnetizing current in the transformer of reversed polarity.

It is possible that some use might be made of this connection for applying a voltage test to a transformer or to obtain a desired voltage. It may be interesting to note that by increasing the delta voltage of the reversed tranformer by changing its ratio, the neutral point *O* on the diagram is still further displaced, approaching infinity as the ratio of the reversed transformer approaches twice that of the other two.

Later on, a case of a wrong connection was reported on a system identical to that shown in Fig. 1. In this case, however, the reversed transformer was at the sending end of the line. The results noted were reversal of phase rotation and low voltage. The low voltage was very marked on one phase when no motors were running, but the operation of motors served to boost the voltage on this phase.

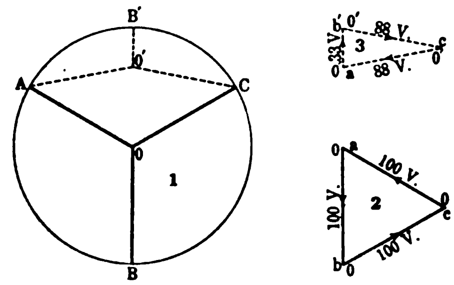

FIG. 6—VOLTAGE DIAGRAMS FOR *Y*-DELTA TRANSFORMER BANK AT RECEIVING END OF LINE
1—*Y* voltages
2—Normal delta voltages
3—Delta voltages when one transformer is reversed at sending end of line

Apparatus was set up in the laboratory to reproduce the above conditions and data obtained to construct voltage diagrams. The theoretical voltage relations for the transformer bank at the receiving end of the line are shown on Fig. 6. These values were very closely approximated by the laboratory test. A study of the voltage diagram for the delta-connected side shows that the phase rotation is reversed and that the voltage is 33 per cent normal on one phase and 88 per cent normal on the other two.

INCREASED TELEPHONE SERVICE IN ATHENS

At the present time a central board serves 1600 telephone subscribers in Athens. This is now found to be insufficient to meet the increasing demands of subscribers, and a committee of technical experts appointed by the Greek Ministry of Communications has recommended the installation of a central board capable of serving 10,000 telephones.

The committee recommended also that subterranean cables be laid to do away with the overhead wires. Inasmuch as the committee believes that four years will be required to complete this work, it has advised that, to meet the emergency, the present system of overhead wires be continued and the board increased from 1600 to 5000 telephone connections, and for this purpose has asked for bids. At the same time bids are requested for the larger central station, which will accommodate 10,000 subscribers. The bids must be submitted to the Ministry of Communications, Athens, Greece.

Commutation on Direct-Current Machines

BY CLAUDIUS SHENFER

Professor of Electrical Engineering, Technical High School, Moscow.

It is well-known, that in direct-current machines with heavy linear armature load (number of ampere conductors per cm. of armature circumference) the commutation occurs under especially heavy conditions; the reactance voltage in such machines rises to a great value and therefore each in accuracy of the compensation of reactance voltage by means of interpoles produces a great additional current in the armature coils short-circuited by the brushes, which causes sparking at the commutator.

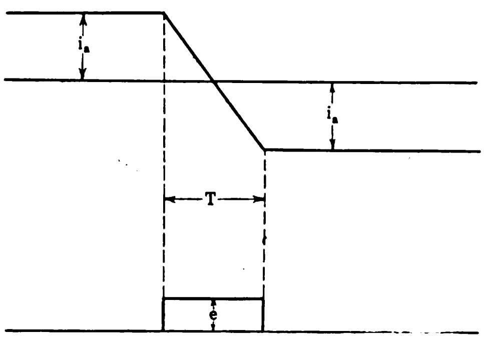

Fig. 1—Current in Armature Coil, Short-Circuited by the Brush (i_a) and E. M. F. of Self-Induction (e)

In machines of low output the reactance voltage compensation at each moment of commutation is not absolutely necessary; in many cases it is sufficient if the reactance voltage is compensated in its *mean value,* but in high-power machines with heavy linear armature load this condition of exact compensation must be fulfilled.

In that case it is necessary to know the reactance voltage curve, its maximum and minimum value, short-circuit time, current per cm. of armature circumference, etc.; this will enable us to find the magnetic induction in the air gap under the interpole and not only its *mean value* but also its shape.

Reactance Voltage

In finding the reactance voltage value we proceed from the supposition that the current variation in the armature coils short-circuited by the brush at the moment of commutation occurs according to the "direct-line" law.

This supposition greatly simplifies the question, because the e. m. f. induced by the current variations remains constant during the whole period of commutation, as is shown in Fig. 1.

The curve of the resulting e. m. f. induced in the armature conductors in the moment of commutation greatly differs from the reactangular shape shown in Fig. 1; this depends upon the mutual induction of the conductors lying in one and the same slot and also in the adjacent slots; further on we will denote this resulting e. m. f. by "reactance voltage" in order to distinguish it from the "self-induction e. m. f." generated in the conductor by the alteration of its *own* magnetic flux.

Supposing the mutual induction coefficient for the conductors lying side by side in one slot equals 1, it is possible to find the e. m. f. induced in each conductor during the commutation, as is shown in Fig. 2; in this figure is shown, for example, the reactance voltage for a Gramme armature with three conductors in one slot; from this figure we see that at first the turn formed by conductor 1 is short-circuited by the brush, the current in this conductor varying according to the curve 1-1; after an interval of time, when the commutator has moved the distance of one commutator pitch β, the commutation begins in conductor 2, and finally after the same interval of time β, in conductor 3; the e. m. fs. of self-induction induced by the variation of its own magnetic flux in the conductor 1, 2, 3 are shown in Fig. 2 in the shape of rectangles A_1, A_2, A_3 displaced on the commutator pitch β. In order to find the resulting e. m. f. (reactance voltage) it is necessary to add the ordinates of the three curves A_1, A_2, A_3; this gives the staggered curve β—the reactance voltage curve; the curve of the e. m. f. induced in the conductor 1 is

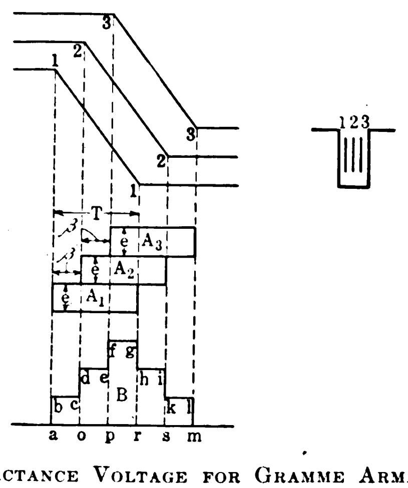

Fig. 2—Reactance Voltage for Gramme Armature with Three Conductors in One Slot (Curve B)

represented by the staggered curve: *a, b, c, d, e, f, g, r,* the curve of the e. m. f. in the conductor 2 by *o, d, e, f, g, i, s* and that in conductor 3, by *f, g, h, i, k, l, m.*

Thus the maximum value of the reactance voltage e_{mx} under the conditions shown in Fig. 2 will be: $e_{mx} = 3\,e$; the value of the e. m. f. of self-induction e may be determined in the following way. Denoting i_a the current strength in each conductor of the armature winding, L the coefficient of self-induction of the armature coil, and T the period of commutation, the e. m. f. of self-induction is $e = L\,2\,i_a/T$ (straight line commutation); inserting in the above expression

$T = b/v$, where b is the width of the brush reduced to the periphery of armature[1] and v = the peripheral speed of the armature, we get $e = L \dfrac{2\, i_a\, v}{b}$

The self-induction coefficient of one armature coil L in this last formula may be determined as follows: $L = w^2\, l . \lambda$, where l is the length of the armature iron in cm., and λ the coefficient of the slot-leakage conductivity.

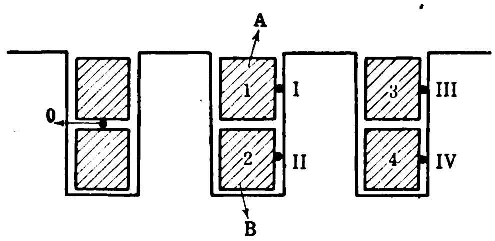

Fig. 3—Double-Layer Drum Winding

Then we have:

$$e = \frac{w^2\, l\, \lambda\, 2\, i_a\, v}{b}\ ;$$

the product $i_a\, w$, which represents the number of ampere turns in one armature coil, we may express as follows:

$$i_a\, w = \beta\, A\, S,$$

where β is the commutator pitch reduced to the periphery of the armature[2] and $A\,S$ is the linear load of the armature in amperes per cm. Comparing this expression with the preceding one, we have:

$$e = \frac{2\, w .\, v .\, \beta .\, A\, S .\, \lambda .\, l}{b}$$

inserting in this formula $b/\beta = n$ = number of commutator bars, short-circuited by the brush, we finally have:

$$e = 1/n \,.\, 2\, w \,.\, v \,.\; A\, S \,.\, \lambda \,.\, l \,. \qquad (1)$$

Chord-Drum Windings

With the drum armature type, which has two layers of winding, we must consider the mutual inductance of the conductors lying in the slot not only side by side, but also in the conductors lying one under the other in different layers.

Let e_1 = e. m. f. of self-induction generated in conductor 1 of the upper layer (A in Fig. 3).
e_2 = e. m. f. of self-induction generated in conductor 2 of the lower layer (B in Fig. 3).

The difference between the values e_1 and e_2 is caused by the difference in value of the slot-leakage coefficient for the conductors lying in the upper and the lower part of the slot; according to the tests made by the author, the mean ratio may be approximately $e_2/e_1 = 2.3$. In the case of double-layer drum winding, besides e_1 and e_2 the following e. m. fs. must be considered:

$k_{31}\, e_1$ = e. m. f. of mutual induction in conductor 1 of the upper layer generated by the alternation of the current in conductor 3 in the upper layer of the adjoining slot (Fig. 3).
$k_{21}\, e_2$ = e. m. f. in conductor 1 generated by conductor 2 in the lower layer.
$k_{41}\, e_2$ = e. m. f. in conductor 1 generated by conductor 4 in the lower layer.
$k_{42}\, e_2$ = e. m. f. in conductor 2 generated by conductor 4 in the lower layer.
$k_{12}\, e_1$ = e. m. f. in conductor 2 generated by conductor 1 in the upper layer.
$k_{32}\, e_1$ = e. m. f. in conductor 2 generated by conductor 3 in the upper layer.

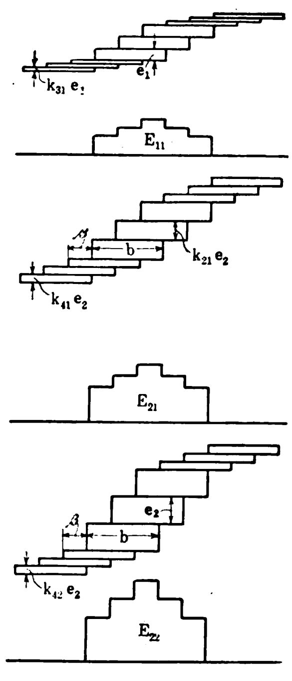

Fig. 4—E. M. Fs. Generated in Conductor of the Upper Layer (E_{11}, E_{21}) and E. M. Fs. in Conductor of the Lower Layer (E_{22}, E_{12})

In Fig. 4 is shown the graphical method of plotting the resulting e. m. f., when there are six conductors in one slot and the brush covers three commutator segments ($b = 3\,\beta$).

The staggered curve E_{11} represents the resulting e. m. f. curve in the conductor 1 of the *upper* layer generated by the conductors of the *upper* layer;

E_{21} represents the e. m. f. curve in the conductor 1

1. $b = b_k\, D/D_k$; where b_k is real width of the brush, D diameter of the armature and D_k diameter of the commutator.

2. $\beta = \beta_k\, D/D_k$, where β_k is real value of commutator pitch.

of the *upper* layer, generated by the conductors of the *lower* layer.

E_{22} represents the e. m. f. curve in the conductor 2 of the *lower* layer generated by the conductors of the *lower* layer.

E_{12} represents the e. m. f. curve in the conductor 2 of the *lower* layer generated by the conductors of the *upper* layer.

In case of full-pitch winding

(when $y_1 = K/p + 1$ and $K/2\,p$ = integer)

the curves E_{11}, E_{21}, E_{22} and E_{12} coincide in phase and the resulting e. m. f. induced in the short-circuited armature coil is the sum of the corresponding ordinates of the above-mentioned curves, as is shown in Fig. 5A.

When plotting Figs. 4, 5 and 6 the following values were taken for the e. m. f. coefficients:

$k_{21} = 0.70$; $k_{31} = 0.28$; $k_{41} = 0.28$;
$k_{12} = 1.20$; $k_{32} = 0.5$; $k_{42} = 0.30$; $e_2/e_1 = 2.30$;

These values were received from the test made by the author, and are described later on.

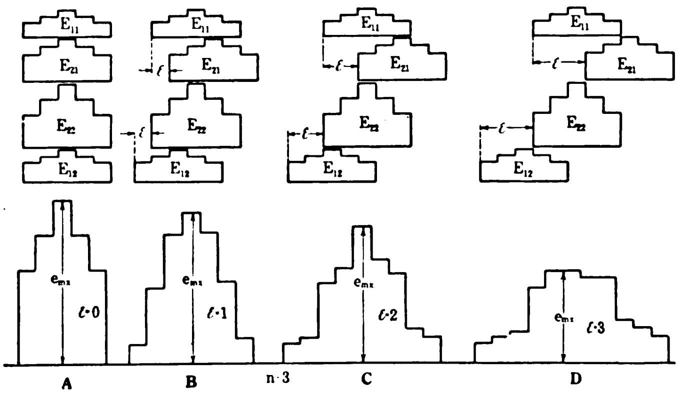

Fig. 5—Reactance Voltages (Resulting E. M. Fs.) Generated in Armature Coils of Chord-Drum Windings with Varied Shortening of the Pitch ϵ

Width of brush n = 3.

In case of drum short-pitch winding the curve E_{12} (see Fig. 5B) must be placed behind curve E_{11} at a distance of ϵ and curve E_{12} before E_{11} at the same distance ϵ, where

$$\epsilon = 1/2\,(K/p + 1 - y_1);$$

(K = number of commutator segments, p = number of pairs of poles, y_1 = first part-pitch of the winding.)

The above is explained by Fig. 6, from which it is seen that conductor 1 lying *over* conductor 2 of the armature coil K is short-circuited by the brush I ϵ commutator bars before the conductor 2, and conductor 2′, which lies in the slot under conductor 1′ is short-circuited on an equal number of commutator bars later than conductor 1′.

In Figs. 5A, B, C and D are shown the reactance voltage curves for ϵ = 0, 1, 2, 3 and $n = 3$[3], and in Fig. 7 the curves of the same values of ϵ but with lesser width of the brush ($n = 2$). From Figs. 5 and 7 it is seen that with the growth of ϵ (*i. e.* with increased shortening of the winding pitch) the maximum ordinate e_{mx} of the reactance voltage curve diminishes and that the value o this curve base correspondingly increases; from these figures it is seen also, that with the growth of ϵ the symmetry of e. m. f. curves is visibly reduced; this is not very desirable, because it requires the asymmetrical level of the interpole shoes.

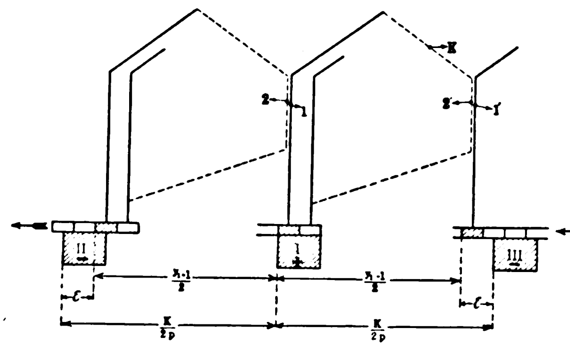

Fig. 6

From Figs. 4 and 5 we may see also the following fact, essential in theory of commutation: The reactance voltages induced in the *upper* and *lower* conductors of the armature coil have *not* an equal value; indeed we see, that the e. m. f. induced in the upper conductor 1 (see Figs. 6 and 4) is composed by adding the ordinates of E_{11} and E_{21} and the e. m. f. induced in the lower conductor 2′, by adding the curves E_{22} and E_{12}, and that the maximum ordinates of E_{22} and E_{12} are greater in the average than the maximum ordinates of the curves E_{21} and E_{11}.

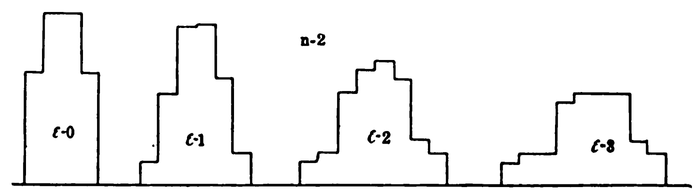

Fig. 7—Reactance Voltages Generated in Armature Coils of Chord-Drum Windings with Varied Shortening of the Pitch ϵ

Width of brush n = 2.

The ratio between these two resulting values of the reactance voltage, according to the author's tests with a 5-h. p. Lahmayer's motor is about 1.40. It is clearly seen that in machines with a double number of commutator segments[4] it is impossible to get an equally good commutation for all the armature coils by means of interpoles.

In machines with a normal number of commutator segments, the magnetic field of interpoles must be of such value, as to compensate *in average* the sum of reactance voltages of the upper and lower conductors of the short-circuited armature coil.

3. The resulting curve $E_{11} + E_{21}$ represents the e. m. f. generated in the upper conductor 1 of armature coil K; the curve $E_{22} + E_{12}$ represents the e. m. f. generated in the lower conductor 2′ of the same armature coil K (see Fig. 6).

4. *i. e.*, with one armature bar for one commutator segment.

In Fig. 8 is plotted the curve of e_{mx} as a function of the value ϵ for $n = 3$.

Full-Pitch Armature Windings

When the part pitch of winding y_1, the number of commutator segments K and the number of pairs of poles p correspond to the conditions of $y_1 = K/p + 1$ and $K/2\,p$ = *whole number*, then, in each conductor of the upper layer the commutation takes place simultaneously with that in the corresponding conductor of the lower layer, lying in the same slot. Therefore to simplify the question, we may suppose

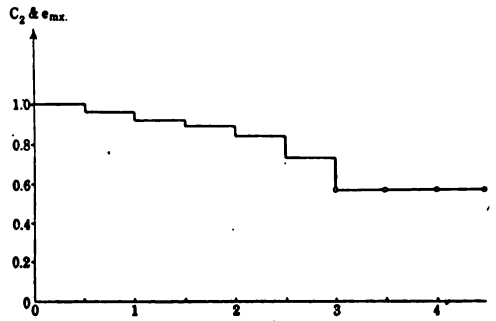

Fig. 8—Influence of Pitch Shortening ϵ upon Value of Reactance Voltage

that each of the upper conductors of the slot is joined with the corresponding lower conductor and instead of the slot a (Fig. 9) we may consider the slot b with half the number of conductors.

In Fig. 10 are shown several curves for the armature with six conductors in one slot (or three "joined" conductors).

In Fig. 10D, the rectangles 7, 8 and 9 represent the *e. m. f. curves of self-induction,* induced in conductors 7, 8 and 9 (Fig. 11). The *resulting* e. m. f. generated in one of the conductors in the slot III

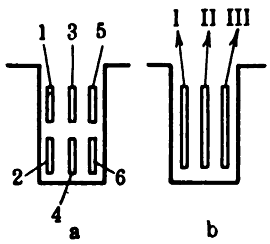

Fig. 9

(Fig. 11) will be greater than *e. m. f. of self-induction* due to mutual induction of other conductors lying in the same slot III and in the adjacent slots II, I and IV, V; the influence of the conductors in the adjacent slots can be found by plotting the rectangles with reduced ordinates $k_1\,e$ placed at a distance from each other equal to the width of commutator segment β (see rectangles 4, 5, 6, 10, 11, 12 in Fig. 10D). The influence of the conductors 1, 2, 3 and 13, 14, 15 (Fig. 11) in more distant slots can be found in the same way graphically, constructing the reactangles of e. m. fs. 1, 2, 3 and 13, 14, 15 (Fig. 10D) with reduced ordinates $k_2\,e$.

According to the author's tests, which will be described later on, in the average, k_1 equals 0.28 and $k_2 = 0.13$. Thus we get the curve of resulting e. m. f. *a b c d e f g h k l m* (Fig. 10D) induced in any conductor, when the latter, with the armature rotation, crosses the commutation zone.

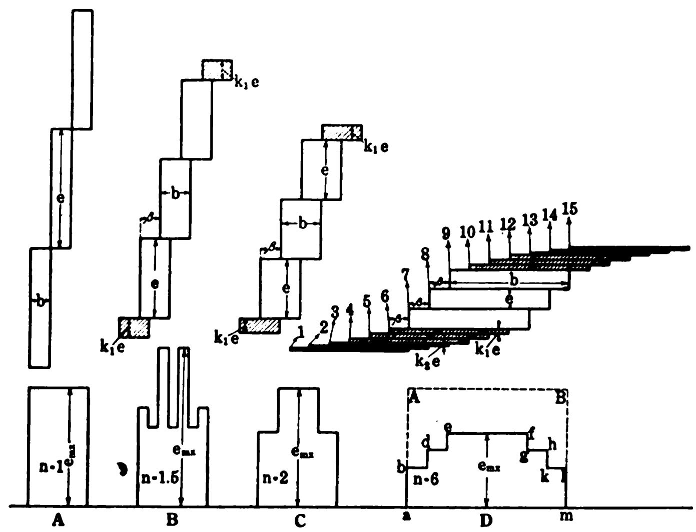

Fig. 10—Reactance Voltages Generated in Armature Coils of Full-Pitch Armature Windings

With various widths of brush.

($b/B = n = 1, n = 1.5, n = 2, n = 6$)

($n_t = 3$)

Let us try to find the expression for th maximum value of resulting e. m. f. e_{mx} (reactance voltage). Denoting the e. m. f. of self-induction by e we may write according to Fig. 10D:

$$e_{mx} = 3\,e + 3\,k_1\,e\,;$$

generally we may write:

$$e_{mx} = n_t\,e + (n - n_t)\,k_1\,e \qquad (2)$$

where $n = b/\beta$ = the number of commutator segments, covered by the brush, and n_t = the number of

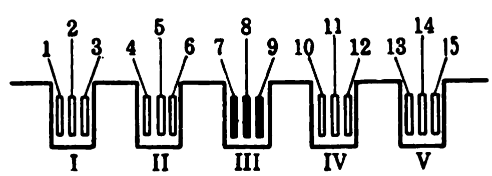

Fig. 11

commutator segments corresponding to one slot. Denoting $N = n - n_t$ we may rewrite this equation as follows:

$$e_{mx} = n_t\,e + N\,.\,k_1\,e = (n_t + N\,k_1)\,e \qquad \textbf{(2a)}$$

The formula (2) is correct only when $n > n_t$; if n is a fraction, the difference $(n - n_t)$ in the expression (2) must be raised to the next *integer*; when $n < n_t$ and n is a fraction, the maximum value of reactance voltage may be expressed by the following formula:

$$e_{mx} = N_1\,e \qquad \textbf{(2b)}$$

where N_1 is the next greater integer to n (when n is an integer, the value N_1 in the equation (2b) is taken as equal to n).

Putting in the equations (2a) and (2b) the expression for e from the equation (1) we find

$$e_{mx} = (n_t/n + N/n\,k_1)\,2\,w\,v\,A\,S\,.\,\lambda\,.\,l \tag{3}$$

and

$$e_{mx} = (N_1/n)\,2\,w\,v\,.\,A\,S\,.\,\lambda\,.\,l \tag{4}$$

Thus we may write

$$e_{mx} = C\,.\,2\,w\,.\,v\,.\,A\,S\,.\,\lambda\,.\,l \tag{5}$$

where $C = n_t/n + N/n\,k_1$ (6)
(when $n > n_t$)

and $C = N_1/n$ (7)
(when $n < n_t$)

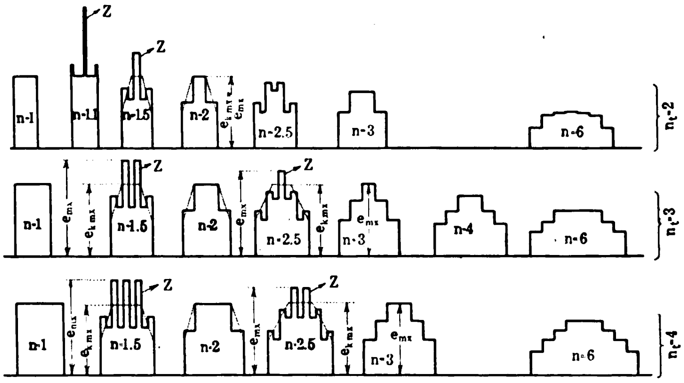

Fig. 12—Reactance Voltages Generated in Armature Coild of Full-Pitch Armature Windings

With various widths of brush (n) and varied number of commutator segments for one slot (n_t).

The formula (5) differs from the well-known formula of Prof. Pickelmayer[5] by the presence of the multiplier C.

In the ideal case of $k_1 = k_2 = 1$, (which never occurs in practise) that is when the coefficient of mutual-induction for conductors lying in different slots equals 1, the formulas (2a) and (5) become:

$$e_{mx} = n\,.\,e$$

and $e_{mx} = 2\,w\,.\,v\,.\,A\,S\,.\,\lambda\,.\,l$.

In this case, instead of the staggered curve of reactance voltage, we get the reactangular shape $a\ A\ B\ m$ in (Fig. 10 D), where the maximum and average values of reactance voltage coincide.

For this ideal case the coefficient C in the equation (5) becomes equal to 1 and the author's equation (5) becomes identical with the equation of Prof. Pichelmayer.

Pichelmayer's equation has been recently very much discussed in the technical literature[6]; the absence of the width of brush in Pichelmayer's formula raised the greatest criticism. One group of scientists (Pichelmayer and others) supposed that the mean value of reactance voltage does not depend practically on the number of commutator segments crossed by the brush and, that therefore it is quite possible to use Pichelmayer's formula, in which the width of brush is not given.

The other group, (Lamme, Niethammer and others) suppose that it is quite impossible to neglect the relation between the reactance voltage value and the width of the brush when calculating the interpoles.

As will be seen later on, both groups were right to a certain degree; the author of this article shows later on, that, when the width of the brush is small, when $n < n_t$, it is quite possible to use Pichelmayer's formula for calculating the interpoles; with brushes of a larger width, when $n > n_t$ it is necessary to put a correcting multiplier C in Pichelmayer's formula.

Reactance voltage curves for different cases ($n_t = 2, 3, 4$ and $n = 1, 2, 3 \ldots . 6$) have been plotted according to the above described method; in Fig. 12 is represented the result of such plotting; from this figure we see that with the increase of the brush-width (see formula 3) e_{mx} decreases; when $n < n_t$ sharp teeth Z appear in the reactance voltage curves, which badly affect the commutation; with the gradual diminution of the width of brush the height of these teeth Z increases and their width decreases, so that when the number of commutator segments covered by the brush is an integer, the tooth takes the limited shape of a straight line (compare for example the teeth Z for $n = 1.5$ and $n = 1.1$, when $n_t = 2$. in Fig. 12).

According to the above described graphical method e_{mx} as a function of the number of segments crossed by the brush $n = b/\beta$ is plotted in reactangular coordinates for $n_t = 2$, 3 and 4 (Fig. 13, 14, 15). From these figures it is seen that this function has the shape

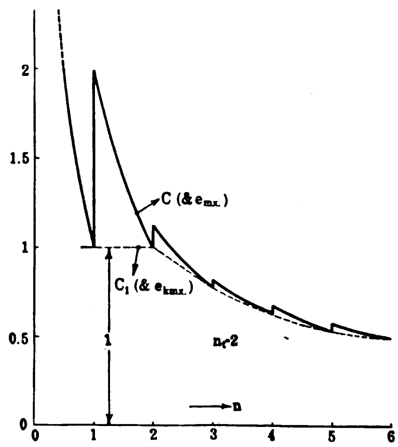

Fig. 13—Reactance Voltage e_{mx} (Solid Line) and Compensating Voltage Generated by the Interpoles e_{kmx} (Dotted Line) as a Funcion of the Brush Width n

Number of commutator segments for one slot $n_t = 2$.

of a toothed curve, approaching the axis of the abscissas with the rise of n; from Figs. 13-15 it is seen that when $n > n_t$ the teeth of the curves become smaller than when $n < n_t$.

Calculation of Interpoles

The interpoles must produce in the neutral zone a magnetic field of such a form and strength as to

5. See *Electrotechnische Zeitschrift*, 1912, p. 3.

6. See *Electrotechnische Zeitschrift*, 1912, pp. 3, 266, 524, 523, 602.

compensate the reactance voltage not only in its mean but also in its instantaneous value. As is seen from Fig. 12, the strict compensation of the reactance voltage is impossible, due to its staggered shape; it is especially difficult to carry out this compensation with the small number of segments crossed by the brush ($n < n_t$) when the teeth Z (Fig. 12) in the reactance voltage curves are strongly developed.

Although we may suppose that in reality the amplitude of this tooth voltage Z strongly diminishes, due

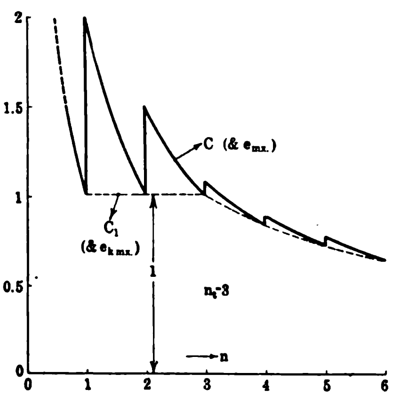

FIG. 14—e_{mx} AND e_{kmx} AS A FUNCTION OF n; $n_t = 3$

to eddy currents, which appear in the iron of the armature teeth and in the solid conductors, still we must in designing the machine try to diminish this tooth voltage.

From Fig. 12 it is seen that the small tooth voltage Z in the reactance voltage curves may be received, when brushes of large width are being used, not less than $n = n_t$; therefore it is necessary, if possible, to use brushes sufficiently wide in order to fulfil this condition($n > n_t$).

The fine lines on Fig. 12 represent the curves of the voltages, which must be generated by the interpoles for the approximate compensation of reactance voltage. The author finds that the maximum value of compensating voltage e_{kmx} may be determined with sufficient exactness for practise according to the equation

$$e_{kmx} = C_1 \,.\, 2\,w\,.\,v\,.\,A\,S\,.\,\lambda\,l \tag{8}$$

where $$C_1 = \frac{n_t}{n} + \frac{(n - n_t)}{n}\,k_1 \tag{8a}$$

(when $n > n_t$)

and $$C_1 = 1 \tag{8b}$$

(when $n < n_t$)

The expressions (**8a**) and (**8b**) must differ from the equations (6) and (7) in the following way: The difference $n - n_t$ must be taken *as it is* and *not* raised to an integer, as we have done in formulas **6** and **7**. The curves of the variation of coefficient C_1 and e_{kmx} in function of n are shown in Figs. 13-15 as dotted lines. In Fig. 12 are shown the e. m. fs. e_{kmx} received from the formula **8** (fine lines). The equations (7) and (8) are correct only for full-pitch windings; for short-pitch windings the equations (5) and (8) can be somewhat changed:

$$e_{mx} = C\,.\,C_2\,.\,2\,w\,v\,.\,A\,S\,.\,\lambda\,.\,l \tag{9}$$

$$e_{kmx} = C_1.\,C_2\,.\,2\,w\,v\,A\,S\,.\,\lambda\,.\,l \tag{10}$$

where the coefficients C and C_1 have their former meaning and the coefficient C_2 represents the result of the pitch shortening and may be found from Fig. 8; when the value of the pitch shortening does not exceed $\epsilon = 1/2$ on basis of Fig. 8 we may find $C_2 = 1$.

Examples: We will take for example the lap winding with $n_t = 3$ and

$$\epsilon = 1/2\,(K/p + 1 - y_1) = 1/4\,;$$

suppose also that for this winding

$$e_0 = 2\,w\,.\,v\,.\,A\,S\,.\,\lambda\,.\,l\,.\,10^{-8} = 1 \text{ volt};$$

when $n = 3.\,2$ commutator segments, we have

$$C = \frac{n_t}{n} + \frac{N}{n}\,k_1 = \frac{3}{3.2} + \frac{1}{3.2}\,0.28 = 1.03;$$

(the value k_1 according to the author's tests is taken as 0.28; N, the next greater integer to $n - n_t = 3.2-3$, is taken equal to 1).

We have

$$C_1 = \frac{n_t}{n} + \left(\frac{n - n_t}{n}\right) k_1 = \frac{3}{3.2} + \frac{3.2 - 3}{3.2} \times 0.28 = 0.96\,;$$

$$C_2 = 1\,;$$

$$e_{mx} = C\,.\,C_2.\,e_0 = 1.03 \times 1 \times 1 = 1.03 \text{ volts};$$

$$e_{kmx} = C_1.\,C_2.\,e_0 = 0.96 \times 1 \times 1 = 0.96 \text{ volt};$$

thus:

$$\frac{e_{kmx}}{e_{mx}} = \frac{0.96}{1.03} = 0.93\,;$$

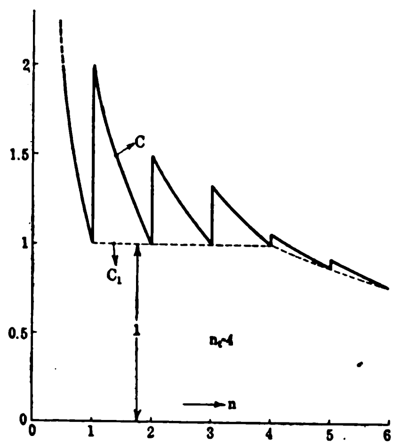

FIG. 15—e_{mx} AND e_{kmx} AS A FUNCTION OF n; $n_t = 4$

that is about 7 per cent of the maximum reactance voltage remains uncompensated. With $n = 2.2$ we get the following values for the coefficients:

$$C = \frac{N_1}{n} = \frac{3}{2.2} = 1.36$$

(N_1 is the next greater integer so $n = 2.2$, that is $N_1 = 3$);

$C_1 = 1$ according to the equation (**8b**);

$C_2 = 1$;

$$e_{mx} = C\,C_2\,e_0 = 1.36 \times 1 \times 1 = 1.36 \text{ volts};$$

$$e_{kmx} = C_1\,C_2\,e_0 = 1 \times 1 \times 1 = 1 \text{ volt};$$

We have: $\dfrac{e_{kmx}}{e_{mx}} = \dfrac{1}{1.36} = 0.73\,,$

that is about 27 per cent of the maximum reactance voltage remains uncompensated (see the teeth Z in Fig. 12).

The shape of the shoe of the interpole must be such as to enable, if possible, the reactance voltage compensation in every period of commutation. From the curves in Fig. 12 it is seen that with a small number of short-circuited segments ($n > n_t$) the best pole shoe is such as shown in Fig. 16, where $a = b$ and $\delta_1 = 2\,\delta$; with a greater number of short-circuited segments it is best to take $a > b$; for a more strict determination of the shape of the shoe it is better first to plot the curves of the reactance voltage and then to choose the shape of the interpole shoe.

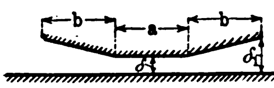

FIG. 16—SHOE OF THE INTERPOLE

EXPERIMENTAL DATA

The problem of finding experimentally the curve of reactance voltage, the author solved in the following way. The armature A of the test direct-current machine[7] was cut and the new ends of the armature winding were joined with the contact rings a and b as shown in Fig. 17; the current from these contact rings by means of the brushes and of conductors was led up to the *immovable armature coil* S placed in the slots of an *immovable* armature. The exploring wire O, lying together with the armature coil in the same slot of the armature (see also Fig. 3) was joined with the strip II of the oscillograph, thus enabling us to observe the curve of e. m. f. generated in this conductor by the variation of current in the armature coil S (the curve of reactance voltage).

The strip of the oscillograph I with the shunt N gave the oscillogram of current curve in the armature coil S.

The switch u and the battery B served for calibrating of the strip II.

The advantage of this method is, that we deal with an *immovable* and approachable armature coil, where all the commutation phenomena take place in the same way as if the coil formed a part of the winding of a *rotating* armature.

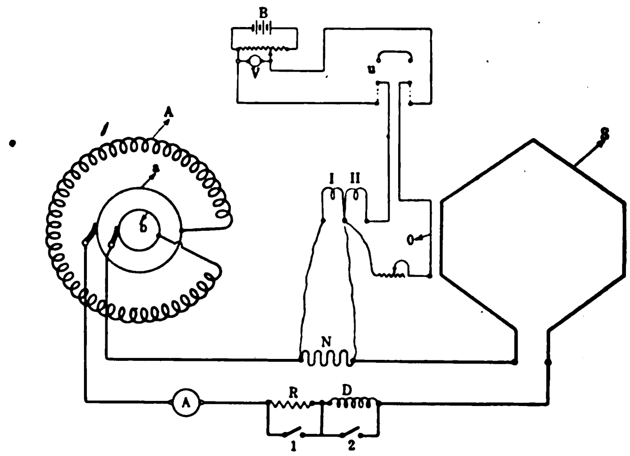

FIG. 17—EXPERIMENTAL SCHEME OF CONNECTIONS

The resistance R and the choke coil D could be connected to the circuit of the coil S by opening the corresponding switches 1 and 2, and enabled us to find the influence of additional resistance and additional self-induction in the short-circuited armature coil on the commutation phenomena.

THE REACTANCE VOLTAGE CURVES

In Figs. 18 to 26 are shown the oscillograms of reactance voltage and current in the armature coils.

In order to vary the current strength and the period

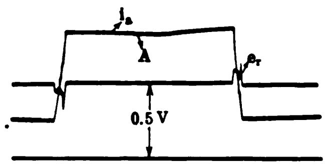

FIG. 18—OSCILLOGRAMS OF REACTANCE VOLTAGE e_r AND CURRENT i_a

i_a = 15 amperes.
n = 300 rev. per min.
Interpoles excited.

of commutation, the direct-current machine (the armature winding of this machine is denoted by A on Fig. 17) was started as a motor; the variations of speed of the motor and consequently the variations of the period of commutation were obtained by the variation of the excitation current of the machine; the variations of the current strength in the tested armature coil S were obtained by the torque variations on the shaft of this machine.

In the slots of the stationary armature were placed

7. The experiments were made with a "Lahmeyer" shunt-wound motor, of which he following are the specifications:

Horse power	5
Terminal voltage	100 volts
Current	5 amperes
Speed rev. per min	200/1200
Number of poles	4
Armature:	
Diameter	312 mm.
Length	750 mm.
Air gap	2 mm.
Commutator:	
Diameter	245 mm.
Number of segments	207
Number of brush spindles	4
Number of brushes per spindle	2 (10 × 20) mm.
Armature Winding:	
Series drum winding in	69 slots
Number of conductors per slot	12
Number of armature conductors	828
Commutating Poles:	
Width of pole	22 mm.
Length of pole	110 mm.
Winding	68 turns per pole

the armature coils; the exploring conductor O (Fig. 17) was placed in the slot at half the height of them (see also Fig. 3. In all tests the length of the exploring conductor was equal to the length of the stationary armature. The dimensions of the stationary (ton wound) armature are the following: Diameter, 250 mm.; length, 110 mm.; number of slots, 40; slot dimensions, 10 × 26. The tested armature coils had

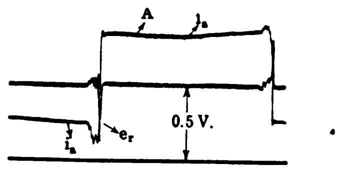

FIG. 19—OSCILLOGRAMS OF REACTANCE VOLTAGE e_r AND CURRENT IN ARMATURE COIL i_a
i_a = 15 amperes.
n = 300 rev. per min.
Interpoles not excited.

three turns in series; the diameter of the conductors was 2.5 mm. In order to damp the natural vibration of the oscillograph strip castor oil was used.

In Fig. 18 is shown the current curve i_a in the armature coil and the reactance voltage curve e_r, the speed of the motor being $n = 300$ rev. per min., and the strength of current $i_a = 15$ amperes (the interpoles were excited).

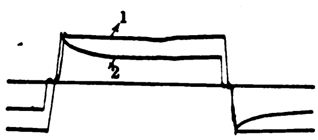

FIG. 20—CURRENT OSCILLOGRAMS WITH THE ADDITIONAL RESISTANCE (2) AND WITHOUT IT (1)

In Fig. 19 are shown the curves taken at the same current $i_a = 15$ amperes and at the same speed, $n = 300$ rev. per min., but with the interpoles not excited; comparing Figs. 18 and 19 we see that with the interpoles not excited the shape of the reactance voltage curve changes strongly and the maximum value of reactance voltage rises from 0.16 volt to 0.41 volt, *i. e.*, 2.56 times.

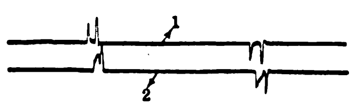

FIG. 21—REACTANCE VOLTAGE GENERATED IN ARMATURE COIL WITH THE ADDITIONAL RESISTANCE (1) AND WITHOUT IT (2)

In Fig. 18 is seen the saddle-shape curve of reactance voltage. This shape may be explained by two causes: By a great ohmic resistance of the tested armature coil, and by non-coincidence in the shape of the e. m. f. curve, generated by the interpoles, and the reactance voltage curve; the first supposition is confirmed by Fig. 21 and the second by Fig. 22.

In Fig. 21 are shown two oscillograms: Below, the oscillogram of reactance voltage for the tested armature coil; and above, in the oscillogram of the reactance voltage in the same armature coil but with the introduction of additional resistance $R = 1.2$ ohms (Fig. 17). As is seen from the oscillograms, with the presence of the additional resistance R the saddle-shape of the reactance voltage curve is more projected.

In Fig. 20 are shown the current oscillograms with the resistance R and without it, (1, the curve without R; and 2, the current curve with $R = 1.2$ ohms).

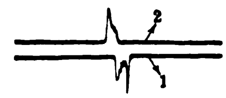

FIG. 22—REACTANCE VOLTAGE
1—Brushes on the neutral zone.
2—Brushes displaced relatively to the neutral.

The curve lineal shape of the line 2 (Fig. 20) may be explained in the following manner: At the rotation of the armature with an additional resistance R in an armature coil the ohmic resistance of each armature circuit in parallel will vary periodically, depending on the presence or absence of R in the corresponding circuit; due to such variation of the ohmic resistance the strength of the current in each parallel circuit must vary; the variation of current due to a great self-

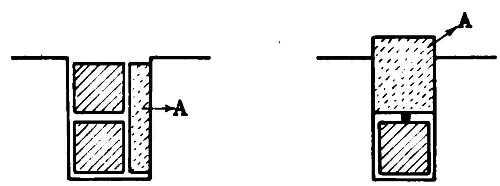

FIG. 23 AND 24—ARMATURE SLOTS WITH SOLID COPPER IDLE CONDUCTORS A

induction of the armature winding cannot take place suddenly, but proceeds according to the exponential curve 2 on Fig. 20. In Fig. 22 are shown two oscillograms: Below, the oscillogram of reactance voltage when the brushes are on the neutral zone; and above, when the brushes are displaced relatively to the neutral on five commutator segments against the direction of armature rotation; as is seen from the upper curve

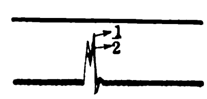

FIG. 25

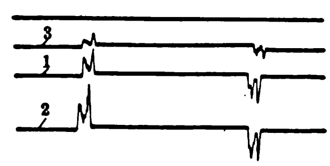

FIG. 26

the saddle-shape character of the reactance voltage curves is lost.

In order to decrease the teeth of the reactance voltage curves (Fig. 12) and in general to decrease the value of the reactance voltage itself, when the conditions of commutation are heavy, it is possible to put in the armature slots besides the conductors of the armature windings the *idle conductors* of solid copper, A (Fig. 23)

in which, when crossing the commutating zone, must develop eddy currents, which produce a damping effect on the slot flux and decrease the reactance voltage. In order to verify this last supposition the following test was made: Into the slot of the stationary armature was put a solid copper conductor A (area of section, 9×14 mm.) due to which the value of the reactance voltage had been decreased 25 per cent (see Fig. 24). Fig. 25 shows the oscillograms of this test (1, the curve of the reactance voltage at normal conditions; 2, the reactance voltage curve, when a solid copper idle conductor was put into the slot.

THE TRANSFORMATION RATIO OF THE ADJACENT ARMATURE COILS

The exploring wires I, II, III and IV were put into the slots, as was shown in Fig. 3. The armature coil fed by the armature current was placed in the slot in the position B (Fig. 3). In Fig. 26 are shown the corresponding oscillograms taken when $i_a = 15$ amperes and $n = 300$ rev. per min.; according to these oscillograms the following relations between the maximum values of the e. m. fs. generated in the conductors I, II, III were obtained:

$$e_2 : e_1 : e_3 = 14.5 : 10 : 4.1.$$

In the same manner the relations were obtained between the e. m. fs. generated in the exploring wires with the armature coil placed in the position A (see Fig. 3). According to these tests the values of the coefficients were obtained, as given before.

CONCLUSION

In conclusion we may give the following summary:

1. The maximum value of reactance voltage e_{mx} decreases with the growth of the width of the brush b; this relation between e_{mx} and b does not represent a continuous function but is represented by a toothed curve, like that in Figs. 13, 14 and 15.

The maximum value of e. m. f. generated by the interpoles with a small number of segments crossed by the brush ($n < n_t$) does not depend on the width of the brush, but with $n > n_t$ must decrease with the growth of the brush width (see formula **8**).

2. With strongly shortened pitch of the armature windings we get the asymmetrical curve of reactance voltage e_{mx}, therefore it is necessary to avoid such windings; with small shortening of the pitch its influence on the value and the shape of e_{mx} is not very important (see Fig. 8).

3. In order to get a smooth curve e_{mx} without sharp teeth it is necessary to design machines with a great number of slots and few commutator segments n_t for each slot.

We must adhere to the following rule when calculating the width of the brush: *The number of segments n crossed by the brush must be, if possible, not less than the number of commutator segments for one slot n_t.* Following the last rule we get a reactance voltage curve of smooth shape, and consequently an almost full compensation of reactance voltage by the interpoles may be obtained.

WORLD-WIDE ACTIVITY IN STEAM RAILWAY ELECTRIFICATION

Due apparently to the marked increase in price of fuel which has taken place during the past few years, steam railroads all over the world are studying the possibilities of electrification as a means of lowering operating expenses.

Most of the leading countries in Europe have announced plans either to increase the present mileage of electrified steam railways or to carry out such work where hitherto electrification was not regarded as economically feasible. In South America, Brazil and Chile either have work under construction or are about to let contracts for such projects.

In Asia, Japan and India are both making investigations with a view to electrifying certain suburban or heavy-traffic sections. In Australia the suburban lines out of Melbourne have been in process of electrification for some years, and other projects in that country are under discussion. In Africa the question of electrifying steam railways of the Union of South Africa has reached the stage where bids have been invited and are in the hands of the consulting engineers, who are expected before long to place some part of the initial construction contract.

In the past, whenever the question of electrification has been taken up, the matter of increasing the capacity of a section of steam railway has probably been the greater factor, rather than reduction in operating expenses. Now the high price of coal throughout the world has brought the latter factor into the greater prominence.

It is interesting to note that in many of the larger countries abroad the heavy trunk-line electrification projects in the United States have been very carefully studied and are very frequently referred to by foreign consulting engineers in their reports, and that in several instances standard American plans have been adopted practically complete by engineers advising foreign governments on steam railway electrification. It is believed that the experience of American manufacturers in developing reliable heavy railroad equipment in this country will be of considerable help in negotiating a foreign contract.—*Commerce Reports.*

A license has been issued to the Alaskan-American Paper Corporation for a hydroelectric development at Orchard Lake, Revillagigedo Island, Alaska. The installation of 5200-horse power hydraulic turbines is contemplated, the power to be used in the operation of a pulp and paper mill. The elevation of Orchard Lake will be raised 32 feet by a rock-fill dam at its outlet from which water will be conducted through a wood-pipe conduit 2000 feet to the power house. All pulp-wood grinding machines will be directly connected to hydraulic turbines, and all other machinery and appliances in the mill will be electrically driven.

Physical Conceptions of Induction Motor Operation

BY J. LEBOVICI

Designing Engineer, Triumph Electric Company

CONFRONTED by the particular behavior of the single-phase induction motor, it is but natural that in order to familiarize ourselves with it, we should substitute for the direct, the indirect description, and explain the single-phase motor by means of the better known polyphase performance. This indirect method originated by E. Arnold and F. Eichberg and recently modified by B. G. Lamme, looks upon the single-phase induction motor as a special case of the polyphase motor and considers it as a revolving field machine.

Yet in the same manner as it has been found advisable to abandon today the indirect method of describing heat phenomena by means of Black's heat substance, for the direct description through the more general principles of modern energetics, it may be preferable to abandon the explanation of the single-phase motor performance by the polyphase for a more direct method. Of the direct methods, the one originated by Potier

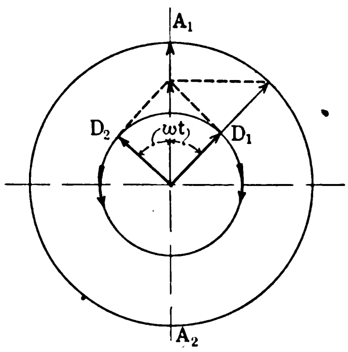

Fig. 1

and G rges and further developed by V. Fynn, McAllister and others, carefully studies the action of the secondary rotating member in the production of a field at right angles in space and time phase to the transformer field.

Since the right angle field is generally called the speed field or cross flux, we can refer to the direct method as the "cross-flux theory" and to the indirect method as the "revolving-field theory."

It is known that the circular current locus or circle diagram determines the performance of the induction motor with an accuracy well within the limits of the practical engineer's needs. The circle diagram is determined when the following three characteristic points are given: The no-load or synchronous speed current, the locked or short-circuit current and the infinite speed current points. Based on either the revolving-field theory or the cross-flux theory analytical expressions for the three characteristic current values can be obtained. It has been shown by E. Arnold that the characteristic current values are the same when calculated from the formula obtained by either method.

V. Karapetoff has shown that the two equivalent diagrams of a single-phase induction motor can be converted into each other, or in other words that the two theories lead to the same performance of a motor with given design constants.[1]

It follows that both methods, when carefully handled lead to the same current locus and, in consequence, to the same motor performance.

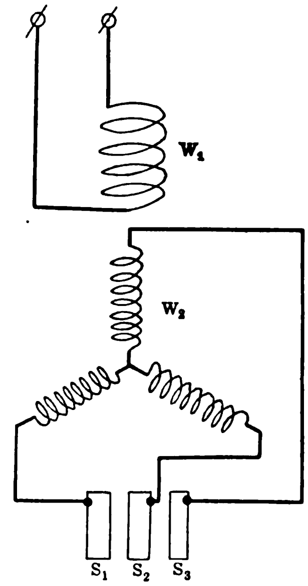

Fig. 2

The revolving-field theory requires more expert handling and is apt to lead to results at variance with experiment unless very carefully interpreted. An instance of such misinterpretation is given below.

The revolving-field theory assumes that a single phase alternating magnetic field $O A$ (see Fig. 1) may be considered as made up of two fields $O D_1 = O D_2 =$

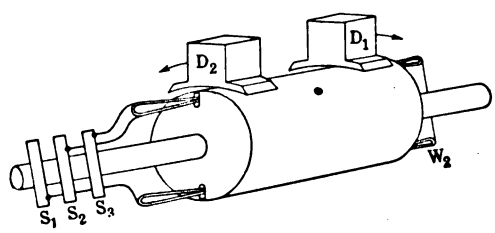

Fig. 3

$\frac{1}{2} O A_1$ of constant value and rotating at uniform speed in opposite directions.

Consider on the basis of this theory, the e. m. fs. generated in the secondary of the slip-ring motor shown in Fig. 2, the primary winding W_1 being connected to a single-phase line and the secondary W_2 being stationary and open circuited. For the sake of

1. See August 1921 Journal of the American Institute of Electrical Engineers, page 640.

better visualization, Fig. 3 has been drawn, showing the rotor core of sufficient length to accommodate the two oppositely revolving fields D_1 and D_2 of constant value. Applying the knowledge obtained from a familiarity with polyphase induction motors to the field D_1 we might expect that it would generate a system of balanced voltages in the secondary winding W_2. Similarly the revolving flux D_2 would produce a system

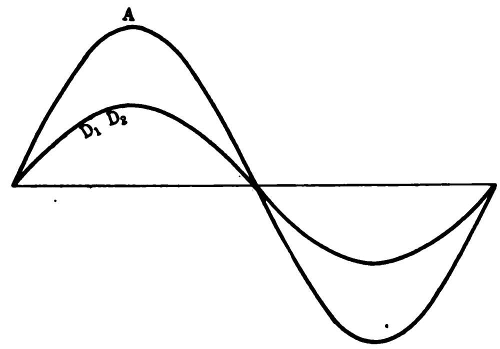

Fig. 4

of balanced voltages in the same windings, W_2. As resultant, we might expect a balanced voltage between slip rings S_1, S_2 and S_3 or otherwise zero voltage.

Experiment as well as unbiased consideration of Fig. 2 will prove that the secondary voltages are neither zero nor balanced and that the effective voltages measured between slip rings S_1, S_2 and S_3 are dependent upon the relative position of the rotor with relation to the stator.

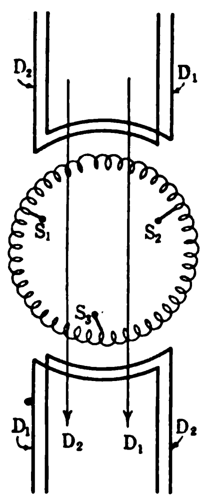

Fig. 5

The discrepancy is due to improper application of the revolving field theory and also shows the defect of the indirect method.

At the instant shown in Fig. 4 and Fig. 5 the magnetic flux A, set up by the primary winding W_1, is at its maximum value. According to Fig. 1, the two component fields D_1 and D_2 each of half a value will coincide both in space (see Fig. 5) and time (see Fig. 4) value. Since in Fig. 5 at the instant considered the fields D_1 and D_2 are both positive with respect to the rotor winding W_2 and rotating in opposite direction the instantaneous value of the e. m. fs. generated in W_2 will be zero.

A quarter of a period later the value of the flux A has decreased to zero and according to Fig. 1, the rotating fields D_1 and D_2 will have the time and space values shown in Figs. 6 and 7. If D_1 is considered positive with respect to the rotor windings W_2 the field D_2 will have to be considered negative. As field D_1 is positive and traveling clockwise while the field D_2 is negative and traveling counter clockwise the e. m. fs. generated in the windings W_2 will add up along a vertical axis in Fig. 7. It is evident from

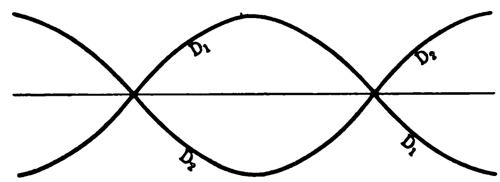

Fig. 6

Fig. 7 that the generated e. m. fs. add between slip rings S_1-S_3 and S_2-S_3 but oppose each other between slip rings S_1 and S_2. This explains why the effective voltages measured between slip rings S_1, S_2 and S_3 under the assumed conditions will be unbalanced.

Proceeding by the direct method we would look upon Fig. 2 as a static transformer, having the secondary open circuited, and since the various secondary phases are not in the same inductive relation with respect to the primary winding we would naturally expect unbalanced secondary voltages.

In deriving the induction motor performance (polyphase and single-phase motors alike) by means of the

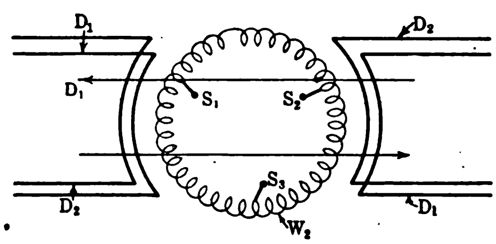

Fig. 7

revolving-field theory, we lost track of the important part played by the secondary leakage in the motor performance. The action of the secondary leakage in improving the power factor of all induction motors is not appreciated and the means for improving the power factor of induction motors by the use of phase advancers or the substitution of a commuted secondary winding for the short-circuited rotor windings are not apparent. On the other hand when proceeding by the cross-flux theory, these phenomena are quite evident. This is one reason why the action of the polyphase induction motors (and of single-phase induction motors without and with commutators)

should be studied by the direct method rather than in a roundabout way by means of the rotating-field theory.

The only reason for deriving the single-phase motor performance from the polyphase instead of going back to fundamental laws as is done by the adherents of the cross-flux theory is the belief that the underlying polyphase motor principles are so well understood. On the other hand it may be pointed out that before the polyphase induction motor is well understood a familiarity with the principles of the static transformer action as well as of the direct-current motor action is necessary. Taking further into consideration that the revolving-field theory is abandoned when we begin to deal with the single-phase commutator motor and that the operation of any type of motor can be derived from fundamental principles without recourse to the revolving-field theory, it would seem logical to derive the polyphase motor performance from fundamental principles without the use of the revolving-field theory.

Considering that science in general and applied science have as a goal a greater economy of thought, it follows that of the two theories, the direct method covering a greater field of phenomena should be given preference in all cases.

From a scientific as well as pedagogical point of view the writer believes that the direct method should be used in deriving the polyphase and single-phase motor performance and obviate the necessity of describing the polyphase motor by the indirect method, then modify this method to suit the single phase induction motor and abandon it when we come to investigate the single-phase commutation motor.[2]

PLANT ADDITIONS BY SOUTHERN CALIFORNIA EDISON COMPANY

During the past year, the Southern California Edison Company has made at three points additions to its hydroelectric plant system totaling 92,000 horse power. These additions consist in Kern River number three plant rated at 40,000 horse power, a new 22,000-horse power generator in Big Creek number two plant, and Big Creek number eight plant rated at 30,000 horse power. According to the Edison Company, the completion of Big Creek number eight plant will remove all possibility of a power shortage this fall during the period when plants without storage are operating at reduced output due to low stream flow. The plant, which is located on the San Joaquin River at its junction with Big Creek, was put into operation on August 12, construction work on the building and in the installation of apparatus normally requiring one year having been completed within three and one-half months. This is the first plant constructed on the Edison System and will probably be the first plant in the world to be put into operation utilizing transmission electrical pressure as high as 220,000 volts. The Edison Company in conjunction with Professor Ryan of Leland Stanford University has been carrying on extensive experiments with the purpose of perfecting its plans to convert the present Big Creek line from an operating electrical pressure of 150,000 volts to 220,000 volts. It is probable that operation at the higher voltage will be accomplished during next year. In the meantime energy from Big Creek number eight plant will be transmitted at 150,000 volts. Transformer equipment for the power house was purchased so that it would be possible to operate temporarily at 150,000 volts, and later on with the conversion of the Big Creek line to the higher electrical pressure to deliver the output from this plant at 220,000 volts. Increasing the voltage on the Big Creek lines from 150,000 to 220,000 volts will double their capacity to transmit energy at a cost much below the duplication of another set of 150,000-volt transmission lines. Economy in transmission costs is the end to be accomplished by the conversion of the present Big Creek lines to the higher operating voltages.

The California Railroad Commission has authorized the Southern California Edison Company to construct an additional plant in the Big Creek hydroelectric development, to be known as Big Creek power house number three. One hundred fifty thousand kilowatts capacity is planned for this power house. Two generating units of approximately 25,000 kilowatts each will first be installed.

A forebay reservoir will be created by a diversion dam on the main San Joaquin River, diverting the waters to the power house intake through a tunnel 23 feet in diameter and approximately six miles in length. The ultimate supply will be 500,000 acre-feet, at approximately 7000 feet elevation and 825 feet total effective head at the turbines. This enormous supply of water available for power purposes throughout the entire year will come from the combined capacity of Huntington Lake, Shaver Lake, the main San Joaquin River and a system of reservoirs to be constructed for conserving and delivering the waters of several smaller sources.

One million barrels of fuel oil, the consumption of steam plants necessary to produce the equivalent amount of electrical energy, will be saved by an output from this power house of 204,000,000 kilowatt-hours of electricity during 1923. Less than five mills per kilowatt-hour is the estimated cost of production of electric current by the initial development. This cost will be reduced by the ultimate development to slightly in excess of two mills, as compared with an average cost of seven mills per kilowatt-hour for steam-generated current.

The first unit is planned for completion in April, 1923, and the second unit in July of the same year. An expenditure of $11,500,000 will be required up to that time. The cost of the complete development is placed at $17,500,000.

2. The application of the direct method to various types of motors has been shown in a series of articles entitled "Power and Torque in Electric Motors" published in *The Electrical Review* Chicago, dated Jan. 4, 1919 and subsequent numbers.

Use of the Tangent Chart for Solving Transmission Line Problems

BY RAYMOND S. BROWN

Columbus, Ind.

Introduction

THE general problem of finding the steady-state electrical conditions at some point of a transmission line when they are known at some other point has been a fascinating one for writers, and many schemes, most of them giving approximate solutions, have been proposed for lessening the labor of solving such problems. Dr. A. E. Kennelly has shown that the exact solution of such problems is most simply given by the use of hyperbolic functions and he has been a pioneer in the application of these functions to transmission line problems. About five years ago the writer devised a method, based on hyperbolic functions, for obtaining the exact solution, by applying them in such a manner that the use of tables is unnecessary, provided a special diagram, called a tangent chart, is available. The chart is entirely general in its application, not depending on any particular frequency or length of line. It was described in an article in French, prepared by Messrs. Marius Latour and Geo. Viard from notes furnished them by Dr. C. O. Mailloux, which was published in *La Revue Générale de l'Electricité*, July 20, 1918. The very favorable consideration which the method received in Europe, and the demand for the publication of a description of the method in the English language, led the writer to take up its study anew, recently, with the idea of improving it, and extending its applicability and practical usefulness. The result is the present paper, which contains an entirely new presentation of the method, in its latest and most complete form.

General Considerations

In any system of conductors for the transmission of electric power, the dielectric plays just as important a role as does the conductor itself. The dielectric, or shunt, constants, conductance and electrostatic capacity, are always present, even though their effects may be insignificant when compared with those of the series constants, resistance and inductance. It is only when the shunt effects are intensified by high voltage, high frequency, or the use of some dielectric other than air, that we must take the shunt constants into account in the solution of transmission line problems. If a line possessed series constants only, or shunt constants only, the fact that these constants were uniformly distributed over the length of line, would have no significance, and problems involving such a line could be solved by the simple application of Ohm's law. Where, however, both kinds of constants are taken into account, their distributed nature must be recognized to get the true solution. Ohm's law can then be applied to a differential length of line, only. The result is, that the expressions for current and voltage, as obtained by integration, are hyperbolic functions of the length of line. In the case of alternating-current transmission, all quantities involved are complex numbers or vectors. In the case of power lines, whose length embraces only a small part of the length of a wave, approximate solutions are frequently used, based upon the expansion of these functions into series. Such approximations do not require the use of tables and give results quite close enough for many purposes provided harmonic frequencies do not need to be taken into account. In the case of telephone lines the length of line embraces an appreciable part of the length of a wave, due to the higher frequency, and approximate solutions are practically never allowable.

In place of the algebraic solution, the writer proposes the use of a chart which will show graphically the electrical conditions at any cross-section of a transmission line operating in the steady state. This graphical method applies to lines having uniformly distributed shunt and series constants and embraces both power and telephone lines of any length, voltage, frequency, or type of construction.

The solution by chart is both simpler and quicker than the algebraic solution, even where approximate equations are used, and it offers the additional advantage that it presents to the eye a picture of the *exact* electrical condition at *every* point of the line. It lessens the chance for numerical error and aids greatly in studying the operation of a line, as the effect produced by a change in load or line constants is shown almost at a glance, without the necessity for working through a lot of tedious mathematics. One of the greatest advantages, however, of this method is that is enables the quantity, watts, or *effective power* at any point of the line, to be represented geometrically by the location of a point in a plane, so that the power may be read directly, without reference to current or voltage, by the mere projection of this point onto a suitable scale.

In order to understand the theory of this chart a working knowledge of the hyperbolic functions of complex numbers is essential. However, just as a slide rule may be used effectively by one who does not understand logarithms, this chart may be used by those not familiar with hyperbolic functions after they understand the method of procedure. The chart is, in fact, a transmission line slide rule, and its use is similar in many respects to that of the ordinary slide rule. Since it deals with complex numbers in place of scalars it is necessary, however, to construct it in two dimensions in place of one.

Vector Expression

There are two methods in general use for expressing the numerical value of a vector or general number; the rectangular form such as $4 + j\,3$, where $j = \sqrt{-1}$, and the polar form, $5\,\sigma^{j36.8°}$ or, as it is more conveniently written, $5 \underline{/36.8°}$. In problems involving sums and differences, only, the rectangular form is more convenient to handle, and in problems involving products and ratios only, the polar form is preferable. The method of solution presented here involves products and ratios almost exclusively, so all quantities are expressed in the polar form.

Line Constants

Let l = the length of the transmission line in miles.

$z = r + j\,x$ = the impedance per mile of conductor.

$y = g + j\,b$ = the admittance per mile of dielectric.

I and E the vector current and voltage respectively, measured to the neutral plane.

$N = \sqrt{z/y}$, a constant usually called the natural impedance, surge impedance, or characteristic impedance of the line. It is defined as the sending end impedance of an infinite length of transmission line having the same cross-section as the actual line. Its dimension is resistance, ohms.

$a = \sqrt{z\,y}$, is called the propagation constant of the line. Its dimension is L^{-1}. The real component of the propagation constant is called the attenuation constant, since it influences the attenuation of current and voltage per mile. The imaginary component is called the wave length constant, since it influences the phase rotation of current and voltage per mile of line.

$A = a\,l$, is called the complex angle subtended by the line. It is a numeric. The real component is called the attenuation of the line and the imaginary component, the wave length of the line.

The solution of problems relating to the line involves hyperbolic functions of the attenuation, which is thus expressed as a number, and circular functions of the wave length, which may thus be expressed in radians or degrees.

The constants N and a depend upon and replace, in the following analysis, the elementary constants, z and y, which are used in approximate solutions. The elementary constants can usually be found tabulated in electrical handbooks. The constants N and a, so far as the writer knows, have never been tabulated and must be computed from z and y. A table of N and a for various sizes and spacings of open wire would be a valuable addition to the modern handbook as these are the constants used in all exact solutions of transmission line problems.

Fundamental Equations

The differential equations applying to an element $d\,l$ of a transmission line, l being measured from the receiving end, are,

$$\frac{d\,E}{d\,l} = z\,I \qquad\qquad \frac{d\,I}{d\,l} = y\,E$$

The solution of these equations gives,

$$E = E_o \cosh A + N\,I_o \sinh A \tag{1}$$

$$I = I_o \cosh A + E_o/N \sinh A \tag{2}$$

The subscript zero denoting receiving end quantities.

These are the equations ordinarily used for the exact solution. Since they contain both sums and products of vectors they are not well adapted to computation using either the polar or the rectangular form of vector expression. A much more convenient form and one well adapted to solution by chart is obtained as follows:

Let, $$W = \tanh^{-1} E/N\,I \tag{3}$$

$$W_o = \tanh^{-1} E_o/N\,I_o \tag{4}$$

Then,

$$E/E_o = \cosh A + \coth W_o \sinh A$$

$$I/I_o = \cosh A + \tanh W_o \sinh A$$

$$\frac{E}{E_o} = \frac{\sinh (W_o + A)}{\sinh W_o}$$

$$\frac{I}{I_o} = \frac{\cosh (W_o + A)}{\cosh W_o}$$

Let, $$W = W_o + A \tag{5}$$

Whence,

$$E \propto \sinh W \tag{6}$$

$$I \propto \cosh W \tag{7}$$

Voltage and current at any point of a transmission line are thus shown to be proportional, respectively, to the hyperbolic sine and cosine of a complex angle, W, whose hyperbolic tangent is the ratio of total impedance to natural impedance. Furthermore, the angle W increases uniformly by the amount a for every mile of line passed over.[1]

These equations are well adapted to the polar form of expression, the vector addition $W = W_o + A$ being performed graphically by the use of the chart.

The Tangent Graph

The terminus of the complex angle W may be located in a plane corresponding to any known value of the ratio $E/N\,I$. The simplest manner in which to locate this point is to construct a graph or Argand diagram of the function, $\tanh W = \tanh (u + j\,v)$. Such a chart is shown in Fig. 1.

Let $$\tanh W = E/N\,I = T = t \underline{/\phi}$$

t will represent the magnitude or modulus of T and ϕ will represent its direction or argument.

The curves marked with angles in Fig. 1 were plotted by assigning successive constant values to ϕ while t was varied, and the curves marked with numbers were plotted by assigning successive constant values to t while ϕ was varied. The scalar equations from which these two families of curves were plotted were obtained as follows.

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1. The fact that E and I may be expressed as simple hyperbolic sine and consine functions of a complex angle is shown by Dr. A. E. Kennelly in his book "Hyperbolic Functions Applied to Electrical Engineering."

From the vector equation,

$$t\,(\cos\phi + j\sin\phi) = \tanh\,(u + j\,v)$$
$$= \frac{\tanh u + j\tan v}{1 + j\tanh u\tan v}$$

GRAPH OF TANH (u + jv)
s Scale

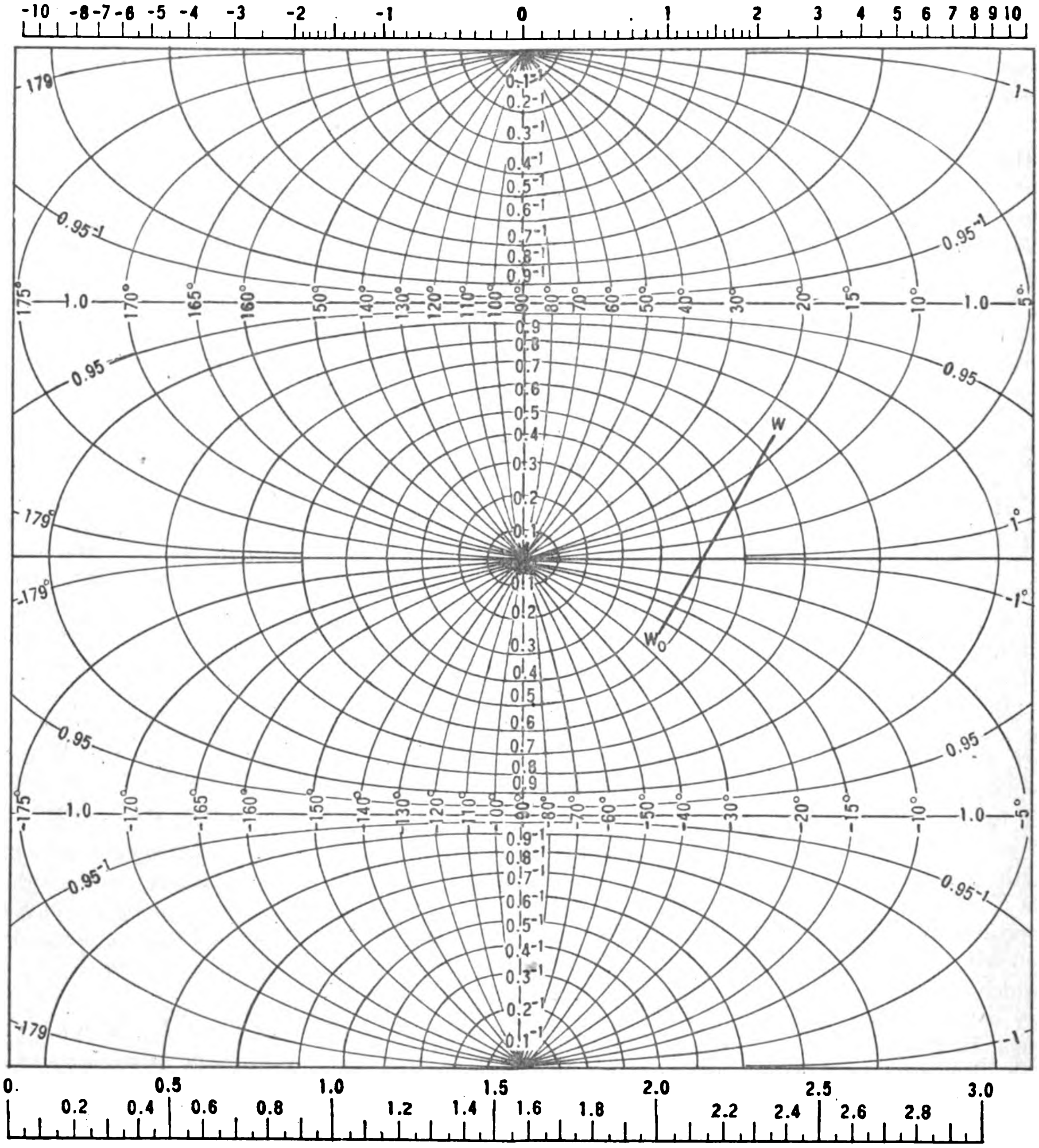


FIG. 1

we get the two scalar equations,

$$\frac{\sin 2\,v}{\sinh 2\,u} = \tan\phi \qquad (8)$$

$$\frac{\cos 2\,v}{\cosh 2\,u} = \frac{1 - t^2}{1 + t^2} \qquad (9)$$

as the equations of these curves.

It will be noted that the two families are orthogonal, which tends to make easy the location of points at their intersection.

The tanh W function is periodic in the direction of the V axis, repeating in the interval $j\,\pi$. It is non-periodic in the direction of the U axis. The graph may thus be thought of as the surface of a cylinder, of diameter equal to unity, which for convenience has been cut parallel to the U axis and spread out into a plane.

Since the circular and hyperbolic tangents bear the relation $\tan W = -j\tanh j\,W$, the graph of tanh W, Fig. 1, becomes also the graph of tan W if the chart is rotated 90 deg. and the numbers on each of the angle

curves reduced by 90 deg. The tan W function is thus periodic in the direction of the real axis and non-periodic in the direction of the imaginary axis.

If we compute the numerical value of the ratio $E/N\,I$ in the polar form we can readily locate the point W by the use of this chart. Supposing known conditions to be at the receiving end of the line, we designate the corresponding value of W by W_o. If we add graphically to W_o the vector $A = a\,l$, by laying it off from the point W_o we arrive at the point W since by equation 5, $W = W_o + A$. The value of $t \underline{/\phi}$ read from the curves at the point W gives us the ratio $E/N\,I$ at the sending end of the line. The angle A being directly proportional to length of transmission line, enables us, should we so desire, easily to find the ratio T, at any intermediate point on the transmission line. Multiplying T by N gives us the sending end impedance E/I at the point W.

Should the point W fall at the center of Fig. 1 it indicates the condition $E/N\,I = 0$ or the corresponding point on the transmission line is grounded, $E = 0$. Should W fall at the other focus of the chart it indicates the condition $N\,I/E = 0$ or the corresponding point on the transmission line is free, $I = 0$.

The region beyond the right and left hand boundaries of Fig. 1 indicates $T = 1$ or the sending end impedance at every point is equal to the natural impedance. This condition exists when the load is of such a character that waves of current and voltage sent out by the generator suffer no terminal reflection. When W travels in this region the phase relation between I and E remains constant and, as W recedes from the V axis both I and E increase in the ratio, σ^a for every mile of line passed over.

The tangent chart illustrates very well the so called Ferranti effect, such as is exhibited by long power lines when operating under light load. In this condition the line acts somewhat like a transformer and converts from low voltage and large current at the sending end to high voltage and small current at the receiving end. An inspection of Fig. 1 shows this effect to be most pronounced when the length of transmission line is a quarter wave length, $A = j\,\frac{1}{2}\,\pi$, as A is then just long enough to span from the $E = 0$ focus to the $I = 0$ focus. The condition $A = j\,\frac{1}{2}\,\pi$ is never fully attained in practise due to dissipation of power in the conductor and dielectric, consequently the vector A always has a real component.

Voltage and Current

We have seen that the tangent chart enables us to find the value of total impedance at any point of the transmission line. We shall now show how voltage and current may be obtained at this point.

Let, $H = \sinh 2\,W = 2 \sinh W \cosh W$

Whence, $H \propto E\,I$ and, since $T \propto E/I$

$$E \propto \sqrt{H\,T} \qquad I \propto \sqrt{H/T}$$

H is given in terms of T by the hyperbolic relation,

$$H = \frac{2\,T}{1 - T^2}$$

Having found from the chart the values of T at any two points on the transmission line, and knowing the values of E and I at one of these points, we can thus find, by simple proportion, the values of E and I at the other point. E and I thus determined are vector quantities, the phase angles of which are measured with respect to the voltage (or current) at some arbitrary point, for instance, the receiving end of the line.

In the great majority of problems we are not interested in the phase of E and I, individually, but only in their relative phase, as it is the angle included between these two vectors which determines the power factor. This relative phase is fully determined by the ratio, T, as found from the chart. We are, however, interested in the individual *scalar* values of E and I. It is possible to find these scalar values much more easily than by the use of the above equation for H, as this equation involves both sums and ratios of vectors and is, therefore, not well adapted to computation.

Let, e = the scalar value of E

i = the scalar value of I

h = the scalar value of H

Then,

$$e \propto \sqrt{h\,t} \qquad i \propto \sqrt{h/t}$$

$$\frac{1}{2\,H} = \frac{1}{T} - T = \frac{1}{t}(\cos\phi - j\sin\phi) - t(\cos\phi + j\sin\phi)$$

$$h = \frac{1}{\sqrt{1/4\,(t + 1/t)^2 - \cos^2\phi}} \qquad \textbf{(10)}$$

We can then find the scalar values of E and I at any point on the line by means of the proportions,

$$\frac{e}{e_o} = \sqrt{\frac{h\,t}{h_o\,t_o}} \qquad \textbf{(11)}$$

$$\frac{i}{i_o} = \sqrt{\frac{h\,t_o}{h_o\,t}} \qquad \textbf{(12)}$$

These are scalar equations and well adapted to computation.

Should the point W fall at the $E = 0$ focus of the chart, we have by equation (10)

$$t = 0 \quad h = 0 \quad \sqrt{h\,t} = 0 \qquad \sqrt{h/t} = \sqrt{2}$$

and should it fall at the $I = 0$ focus we have,

$$1/t = 0 \quad h = 0 \quad \sqrt{h\,t} = \sqrt{2} \quad \sqrt{h/t} = 0$$

In place of obtaining h from equation **10** it may be found more easily by expressing it in terms of u and ϕ thus,

$$H = \sinh 2\,W = \sinh 2\,u \cos 2\,v + j \cosh 2\,u \sin 2\,v$$

$$h = \sinh^2 2\,u + \sin^2 2\,v$$

Eliminating v by means of equation **8**,

$$h = \frac{\sinh 2\,u}{\cos\phi} = \frac{s}{\cos\phi} \qquad \textbf{(13)}$$

The use of this equation requires an additional scale, that of $s = \sinh 2u$, which is shown at the top of the chart. This scale also serves another useful purpose as will be shown later. It is read by projecting vertically from the point W.[2]

Equation **13** becomes indeterminate for all points on the V axis, $u = 0, \phi = \pm 90$ deg., and equation **10** must be used in its stead for such points.

Power Relations

If δ represents the argument of vector N and β the argument of vector I, E being taken as standard phase or zero argument,

$$t \underline{/\phi} = E/N\,I \qquad \phi = -\delta - \beta$$

Let p be the effective power or watts, then,

$$p \propto h \cos \beta = \frac{\sinh 2u}{\cos \phi} \cos(\phi + \delta)$$

$$= \sinh 2u\,(1 - \tan \delta \tan \phi) \cos \delta$$

$\cos \delta$ being a constant, may be dropped from the proportion. Eliminating ϕ by means of equation 8,

$$p \propto \sinh 2u - \tan \delta \sin 2v$$

The power will be zero when

$$\frac{\sin 2v}{\sinh 2u} = \cot \delta = \tan(\pm \pi/2 - \delta)$$

This is the equation of that particular angle curve on the chart, Fig. 1, for which $\phi = \pm \pi/2 - \delta$ or $\beta = \pm \pi/2$

But $\beta = \pm \pi/2$ implies that current and voltage are in quadrature. Hence all points on this particular angle curve represent the condition of zero power factor and this curve may thus be designated the zero power factor wave.

This wave makes the angle δ with the V axis at the origin. Similarly we have a unity power factor wave

$$\frac{\sin 2v}{\sinh 2u} = \tan - \delta \text{ making the angle } \delta \text{ with the } U$$

axis at the origin.

Denoting the abscissa of the zero power factor wave by u' we get,

$$p \propto \sinh 2u - \sinh 2u'$$

$$p \propto s - s' \qquad (14)$$

The result of this analysis is shown graphically in Fig. 2 where the zero power factor wave is shown for one and a half cycles. In this particular case δ is a negative angle.

The inclined straight line represents the locus of the point W. This line, if sufficiently extended, will cut the zero power factor curve in one point and only one. This corresponds to a point on the transmission line at which the power factor is zero but neither current nor voltage is zero. In other words, power is flowing toward this point from both directions, as would be the case with a transmission line fed with power from two generating stations. The dotted line represents the locus of the unity power factor wave, $\phi = -\delta$. This curve will, in general, be intersected in more than one point, each intersection corresponding to the condition of unity power factor on the transmission line.

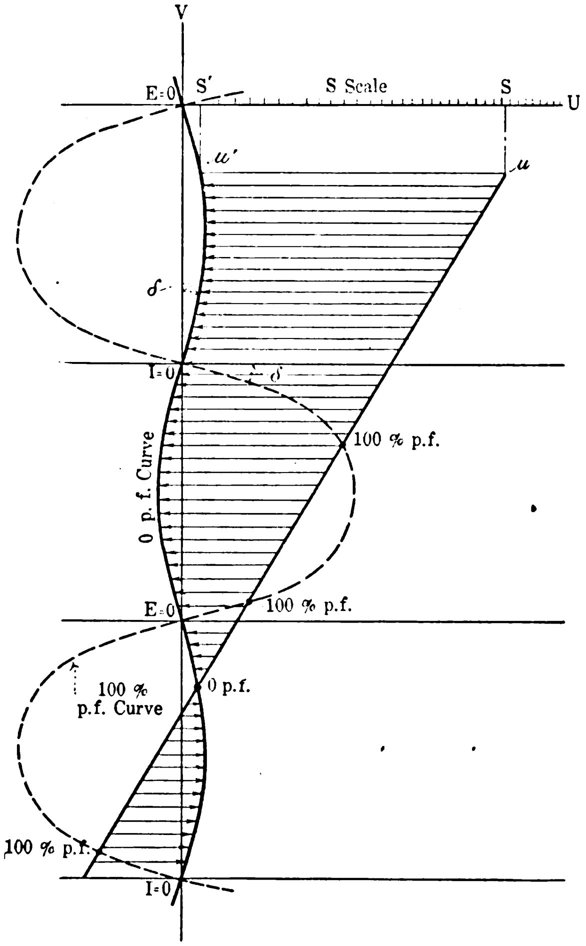


Fig. 2

Since $\sinh 2u$ always increases as u increases, the intercepted horizontal distance, shown shaded on the chart, may be considered as a rough measure of the power at any point.

The exact watt efficiency of any transmission line is given by,

$$f = \frac{s_o - s_o'}{s - s'} \qquad (15)$$

When N, A, and the load impedance are known the

2. If it were possible, without confusion of lines, to superpose on the tangent chart a graph of sinh W or cosh W, in which modulus curves only, were shown, each curve being marked with the parameter used in plotting it, we should have a means of finding the scalar values of E and I without the use of the s scale. This follows from equations **6** and **7**.

The tangent chart, as originally published, under the name of "Transmission Line Coordinate Paper," used this method, the modulus curves being drawn on the back of the chart and read by holding the chart up to transmitted light. It is believed that the present method is simpler, and in addition it permits the chart to be reproduced on an opaque surface.

The article by Messrs. Latour and Viard referred to in the introduction, contains a good description of the tangent chart, its mathematical basis and derivation and the practical use of the original form of tangent chart devised by the writer.

efficiency of any line may thus be very simply found, entirely without reference to current or voltage.

The maximum possible variation of δ is from -45 deg. to $+45$ deg. Thus s' can never be greater than unity, as represented by the projection of the crest of the wave.

Power flow is represented on the chart as always being *toward* the zero power factor wave. The receiving end of any A line which may be drawn on the chart will thus be whichever end of the A line is nearest this curve. Since ϕ usually lies between -90 deg. and $+90$ deg. the point W usually falls on the right side of the V axis and the left end of the A line is thus ordinarily the receiving end.

Maximum Efficiency

We have seen that for every position of the A line in the plane of the chart the corresponding watt efficiency of the transmission line may be readily found by the use of the zero power factor wave and the s scale. As the position of the A line recedes from the V axis the imaginary component of A, or the wave length of the transmission line, has less and less effect on the efficiency, until, when A reaches the region where $T = 1$, the efficiency approaches the constant value,

$$f = \left. \frac{\sinh 2\,(u + c)}{\sinh 2\,u} \right|_{u = \infty} = \sigma^{2c},$$

c being the attenuation. The efficiency, σ^{2c}, is however, the maximum efficiency only in the special case where $\delta = 0$, or the ratio $x/r = b/g$. This of course, includes the case of direct current where both x and b are zero. In all other cases the perturbing effect of the zero power factor wave is such as to produce an efficiency somewhat higher than σ^{2c} at a certain location in the plane. In order to find this particular location it is necessary to vary the position of A with respect to the U and V axes independently and solve the resulting equations simultaneously. This is accomplished as follows.

The efficiency pertaining to any location of the A line is,

$$f = \frac{\sinh 2\,u_o - \tan\delta \sin 2\,v_o}{\sinh 2\,u - \tan\delta \sin 2\,v}$$

u, v being the coordinates of the sending end and u_o, v_o of the receiving end.

Since f is to be a maximum with respect to both u and v,

$$\frac{\partial f}{\partial u} = 0 \qquad \text{and} \qquad \frac{\partial f}{\partial v} = 0$$

whence,

$$(\sinh 2\,u - \tan\delta \sin 2\,v) \cosh 2\,u_o\, \partial u_o = (\sinh 2\,u_o - \tan\delta \sin 2\,v_o) \cosh 2\,u\, \partial u$$

$$(\sinh 2\,u - \tan\delta \sin 2\,v) \cos 2\,v_o\, \partial v_o = (\sinh 2\,u_o - \tan\delta \sin 2\,v_o) \cos 2\,v\, \partial v$$

But, since u and u_o differ by a constant and v and v_o differ by a constant, $\partial u_o = \partial u$ and $\partial v_o = \partial v$

Whence, $f = \dfrac{\cosh 2\,u_o}{\cosh 2\,u}$ and $f = \dfrac{\cos 2\,v_o}{\cos 2\,v}$

Hence, $$\frac{\cos 2\,v_o}{\cosh 2\,u_o} = \frac{\cos 2\,v}{\cosh 2\,u}$$

$$\frac{1 - t_o^2}{1 + t_o^2} = \frac{1 - t^2}{1 + t^2} \quad \text{or} \quad t_o = t$$

Also, $$\frac{\sinh 2\,u_o - \tan\delta \sin 2\,v_o}{\sinh 2\,u - \tan\delta \sin 2\,v} = \frac{\cosh 2\,u_o}{\cosh 2\,u}$$

Replacing u and v by ϕ and t, by the use of equation **8** and **9** and using the relation found above, $t_o = t$,

$$\frac{1 - \tan\delta \tan\phi_o}{1 - \tan\delta \tan\phi} = \frac{\cos\phi}{\cos\phi_o}$$

$$\cos\delta \cos\phi_o - \sin\delta \sin\phi_o = \cos\phi - \sin\delta \sin\phi$$

$$\cos(\delta + \phi_o) = \cos(\delta + \phi)$$

$$\delta + \phi_o = \pm(\delta + \phi)$$

Ignoring the plus sign which gives $W = W_o$ we have,

$$\delta + \phi_o = -\delta - \phi$$

$$\phi_o + \phi = -2\,\delta \qquad \text{or} \qquad \beta_o = -\beta$$

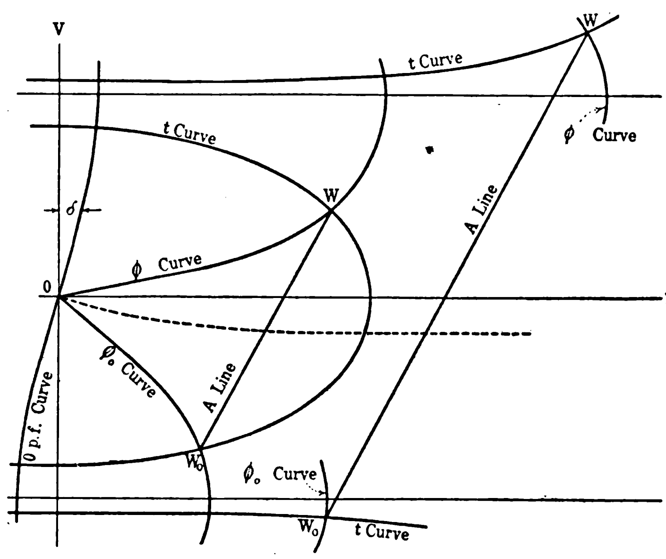


Fig. 3

The result of this analysis may be stated as follows. Any transmission line will operate at its maximum efficiency when the impedances at the opposite ends of the line are symmetrical. That is, the scalar values of the impedances and also the power factors must be equal at the opposite ends of the line but the current must lead the voltage at one end by the same angle that it lags at the other.

The location of the A line on the chart to attain this maximum efficiency may be found by the use of the ϕ, t curves and entirely without numerical computation. This is accomplished as follows, see Fig. 3.

Having laid the A line off along the edge of a strip of paper, move it slowly toward the V axis, being careful to preserve the proper slope and to keep the extremities, W and W_o, of the A line, on the same t curve at any position. The midpoint of the A line will move along a locus represented by the dotted line. Note the algebraic sum of $\phi + \phi_o$ as A approaches the V axis.

When this sum reaches the value $-2\,\delta$, the position of maximum efficiency will have been reached.

Since δ is the argument of the vector $\sqrt{z/y}$,

$$2\,\delta = \tan^{-1} x/r - \tan^{-1} b/g$$

Hence when b/g is greater than x/r, $2\,\delta$ is negative and $\phi + \phi_o$ is positive. The point O, Fig. 3, then represents the $I = 0$ focus of the chart, Fig. 1, because in this region ϕ_o is positive and numerically greater than ϕ.

When b/g is less than x/r, $\phi + \phi_o$ is negative and O represents the $E = 0$ focus.

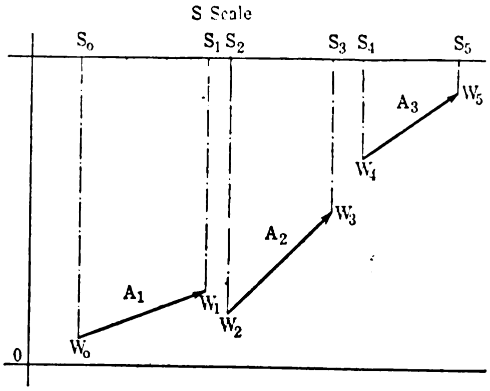


FIG. 4

The construction at the right of Fig. 3 shows the location of A when the length of transmission line is greater than a quarter wave length.

In the case of power lines having no leakage, the A line, for maximum efficiency, lies with its mid-point very near to the $I = 0$ focus. The load current is lagging nearly 90 deg. and the sending end current leading nearly 90 deg. This condition is only attained in practise on light, highly inductive load, such as transformer charging current. At full load the average power line works at somewhat less than maximum efficiency.

Composite Lines

The tangent chart may be used to good advantage for the solution of problems relating to composite transmission lines, that is to say, lines made up of sections in series having different constants, as for example, open wire and cable.

In general the locus of the point W for such a line will be a series of disconnected straight lines, each being the A line for that particular section, see Fig. 4. W_2 is found from W_1 by means of the relation,

$$T_2/T_1 = N_1/N_2$$

N_1 and N_2 being the natural impedances of the sections. I and E are the same on both sides of any junction.

The volt-ampere equation for such a composite line takes the form,

$$\frac{e_5\, i_5}{e_o\, i_o} = \frac{h_1 h_3 h_5}{h_o h_2 h_4}$$

Having thus found T and $e\,i$ at the distant end of the line, current and voltage are completely determined. The various A lines will alter their relative positions in the plane with change of load. Their individual lengths and slopes will remain constant however.

In the special case where the natural impedances of the various sections of line are all the same, the W locus becomes a continuous, broken line, and the line A, Fig. 5, representing the sum of the sections, may be used in their place. It is interesting to note that the terminal load is equivalent in its effect to an imaginary section of line, of the same natural impedance as that of the sections and whose value of A is W_o. The distant end of this imaginary section may be conceived as either grounded or free, depending upon whether the point O is the $E = 0$ or the $I = 0$ focus of the chart.

Series Loads

The solution for irregularly loaded telephone lines may readily be found by the use of the chart. The loads may be either series or shunt.

In the case of series loading, the terminal impedance being known, W_o is determined, Fig. 4. From this point lay off the vector A_1, corresponding to the first section of uniform line. This brings us to the first load at which we obtain the sending end impedance $E_1/I_1 = N_1\,T_1$ on the receiver side of the load. The impedance on the sending side of the load is $(N_1\,T_1 + Z)$ where Z is the impedance of the load. Hence,

$$T_2 = \frac{(N_1\,T_1 + Z)}{N_2}$$

and the point W_2 is determined.

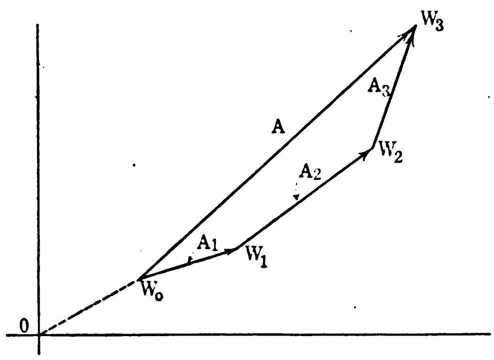


FIG. 5

From W_2 we proceed with the next uniform section of line and so on until all loads and all sections have been passed and we arrive at the final sending end impedance. The addition of impedances may be performed graphically on a separate sheet if desired.

The efficiency of such a loaded line is the product of the efficiencies of all the loads and all the sections. The efficiency of any uniform section of line is given by equation **15**. The efficiency of any series load is,

$$f_s = 1 - \frac{\text{loss}}{\text{input}} = 1 - \frac{r\, i_2^2}{e_2\, i_2 \cos\beta_2}$$

$$= 1 - \frac{r}{t_2\, n_2 \cos\beta_2}$$

where r is the resistance of the load, t_2, n_2, β_2 are measured on the sending side of the load and n_2 is the scalar value of N_2.

Shunt Loading

Lines containing shunt loads are solved in a similar manner except that the admittance is found at the sending end of each load and added vectorially to the admittance of the load. The corresponding formula for T_2 then becomes, $1/T_2 = N_2(1/N_1 T_1 + Y)$, Y being the admittance of the load. The formula for efficiency of a load becomes,

$$f_p = 1 - \frac{\text{loss}}{\text{input}} = 1 - \frac{g\, e_2^2}{e_2\, i_2 \cos \beta_2}$$

$$= 1 - \frac{t_2\, n_2\, g}{\cos \beta_2}$$

where g is the conductance of the load.

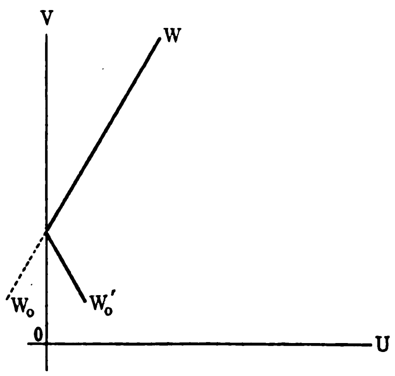


Fig. 6

This same method of solution may be applied to power lines having loads of known admittance tapped off at intervals, except that in this case the efficiency of the loads does not enter as a factor in the total line efficiency.

Direct-Current Lines

In the case of direct-current transmission lines such as cables, having distributed leakage and resistance, the constants N and A become real numbers and the A line lies in the U axis of the chart. The formulas for h, and e and i become,

$$h = s \qquad e \propto \sqrt{s\,t} \qquad i \propto \sqrt{s/t}$$

The similarity in principle between the tangent chart and the ordinary slide rule is quite evident in the case of direct current as both the tangent scale and the A scale consist of real numbers and are capable of being used on slides in the same manner as are the usual logarithmic scales.

The Work Chart

In using the tangent chart for numerical computation it is desirable, for reasons of accuracy, that it be drawn to as large a scale as possible. An inspection of Fig. 1 shows that, so far as the shape of the curves is concerned, regardless of the numbers attached to them, the diagram is symmetrical about the V axis and repeats itself at intervals of a quarter wave length, $\frac{1}{2}\pi$, along the V axis. This fact is taken advantage of in the construction of the work chart, which is an enlarged reproduction of the right central portion of Fig. 1. The curves are plotted to a scale twice as large as would be possible if the entire function were shown.

On the work chart, values of T greater than unity cannot be plotted. Due, however, to the relation,

$$\coth W = \tanh (W \pm j\, \tfrac{1}{2}\pi)$$

we may invert T whenever it is greater than unity, plot the resulting angle, and carry out the solution just as though we were working on the missing half of the chart. Our final result will then be read as $1/T$ or $N\,I/E$, which is the value of $\coth W$.

The left half of the tangent diagram has been omitted from the work chart for the reason that in most practical problems W will lie to the right of the V axis. In case, however, the A line should cross the V axis, it may be shown as reflected from the axis, as in Fig. 6. The value of ϕ as read at W'_0 will then be the supplement of the actual value at W_0. The value of t is the same at both points.

In case the A line runs off the top or bottom boundary of the chart it reappears at the opposite side and continues in the same direction as before, such that if the chart were rolled into a cylinder, parallel to the U axis, the A line would form a helix, see Fig. 7. In this case the A line is broken into two or more parts, as, A_1, A_2, A_3. If points on the line A_1 read the ratio $E/N\,I$ then points on A_2 will read $N\,I/E$, the ratio, T, inverting every time W passes off one boundary and reappears at the other.

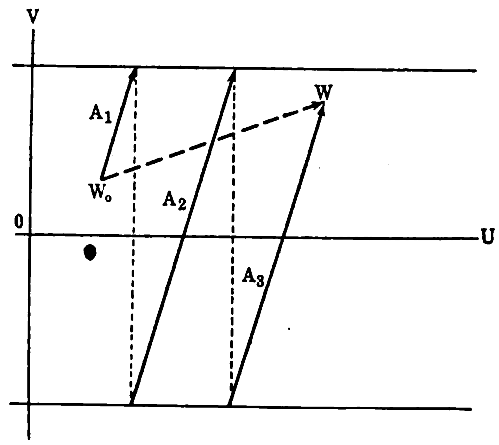


Fig. 7

For very long lines, an effective value of A_e, may be substituted for A. This is a fictitious value of A which will produce the same terminal effects as the actual value. When this substitution is made care must be taken to note whether W_0 and W read the same or inverse ratios of T.

It will be noted that the curves on the work chart are symmetrical about the U axis. This permits a chart of the top half, only, of the work chart to be used

if desired. Such a chart would be only one eighth of a wave length in height and would permit even a larger scale to be used, with a corresponding increase in accuracy. The locus of the point W on such a chart would appear as in Fig. 8. The sign of the angle ϕ would reverse with every reflection from the bottom boundary and the ratio T would invert with every reflection from the top boundary. The point W would follow the same path as would a billiard ball if rolled on a table, the cushions of which represent the boundaries of the chart.

Use of the Work Chart

The work chart, as here presented, may be used for the solution of transmission line problems without drawing upon it if a small triangle, representing the vector, A, be cut out of cardboard and laid upon the chart with its base parallel to the U axis. It may be

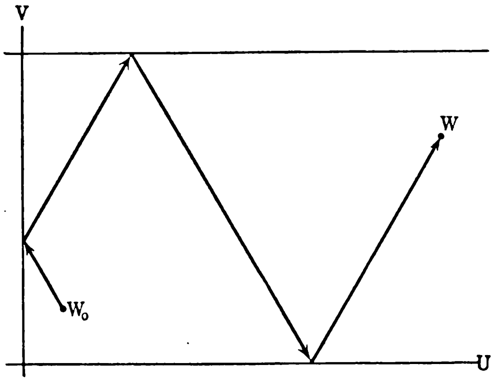


Fig. 8

moved about to represent various electrical conditions on the transmission line and the values of T_0 and T read off at the corners. In place of using cardboard, A may be drawn on a piece of tracing cloth and moved about over the chart. When using the work chart it is desirable to have it attached to a drawing board so that the s scale may be read by projection. The angle α has a possible variation of 90 deg. each way from zero but in most practical problems will be found to lie between 80 and 90 deg.

Numerical Example

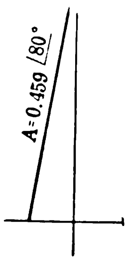
A three-phase power line has the following constants per wire,

$$Z = 60 + j\,165 = 175.5\,/\underline{70^\circ} \text{ ohms}$$

$$Y = 0 + j\,0.0012 = 0.0012\,/\underline{90^\circ} \text{ mhos}$$

Whence, $$N = \sqrt{Z/Y} = 382.5\,/\underline{-10^\circ} \text{ ohms}$$

$$A = \sqrt{Z\,Y} = 0.459\,/\underline{80^\circ}$$



If the voltage to neutral at the load is 60,000 volts and the load current is $90\,/\underline{-20^\circ}$ amperes, find the conditions at the sending end.

Solution

$$\frac{1}{T_o} = \frac{N\,I_o}{E_o} = \frac{382.5\,/\underline{-10^\circ} \times 90\,/\underline{-20^\circ}}{60000} = 0.574\,/\underline{-30^\circ}$$

T_o being greater than unity, the inverse ratio must be used. Plotting the value $1/T_o$ we read $s_o = 1.115$ whence,

$$h_o = \frac{s_o}{\cos\phi_o} = \frac{1.115}{\cos -30^\circ} = 1.288$$

Laying off vector A from the point W_o, we reach W, from which we read the conditions at the sending end,

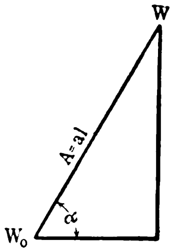


Fig. 9

$$\frac{1}{T} = \frac{N\,I}{E} = .516\,/\,8^\circ$$

$$h = \frac{s}{\cos\phi} = \frac{1.36}{\cos 8^\circ} = 1.373$$

Hence the phase of sending end current with respect to sending end voltage is $\beta = 8 - \delta = 18^\circ$ lead.

The scalar values of sending end voltage and current are found by the use of equations **11** and **12** to be,

$$e = e_o\sqrt{\frac{h\,t}{h_o\,t_o}} = 60{,}000\sqrt{\frac{1.373 \times 0.574}{1.288 \times 0.516}} = 65{,}300 \text{ volts.}$$

$$i = i_o\sqrt{\frac{h\,t_o}{h_o\,t}} = 90\sqrt{\frac{1.373 \times 0.516}{1.288 \times 0.574}} = 88.2 \text{ amperes, scalar value.}$$

The efficiency of transmission is,

$$f = \frac{h_o \cos\beta_o}{h\cos\beta} = \frac{1.288 \times \cos -20^\circ}{1.373 \times \cos 18^\circ} = 92.8 \text{ per cent.}$$

The efficiency may also be found without reference to E or I by equation **15**,

$$f = \frac{s_o - s_o'}{s - s'} = \frac{1.115 + 0.115}{1.36 - 0.035} = 92.8 \text{ per cent.}$$

The zero power factor curve in this case is the 80° wave, since current and voltage are in quadrature at all points on this curve, $\beta = 80^\circ + 10^\circ$.

If we wish to find the sending end voltage and charging current of the above line at no-load, we lay off the A line from the origin $1/T_o = 0$, and read the value of $1/T$ and s at the upper end of the A line, whence,

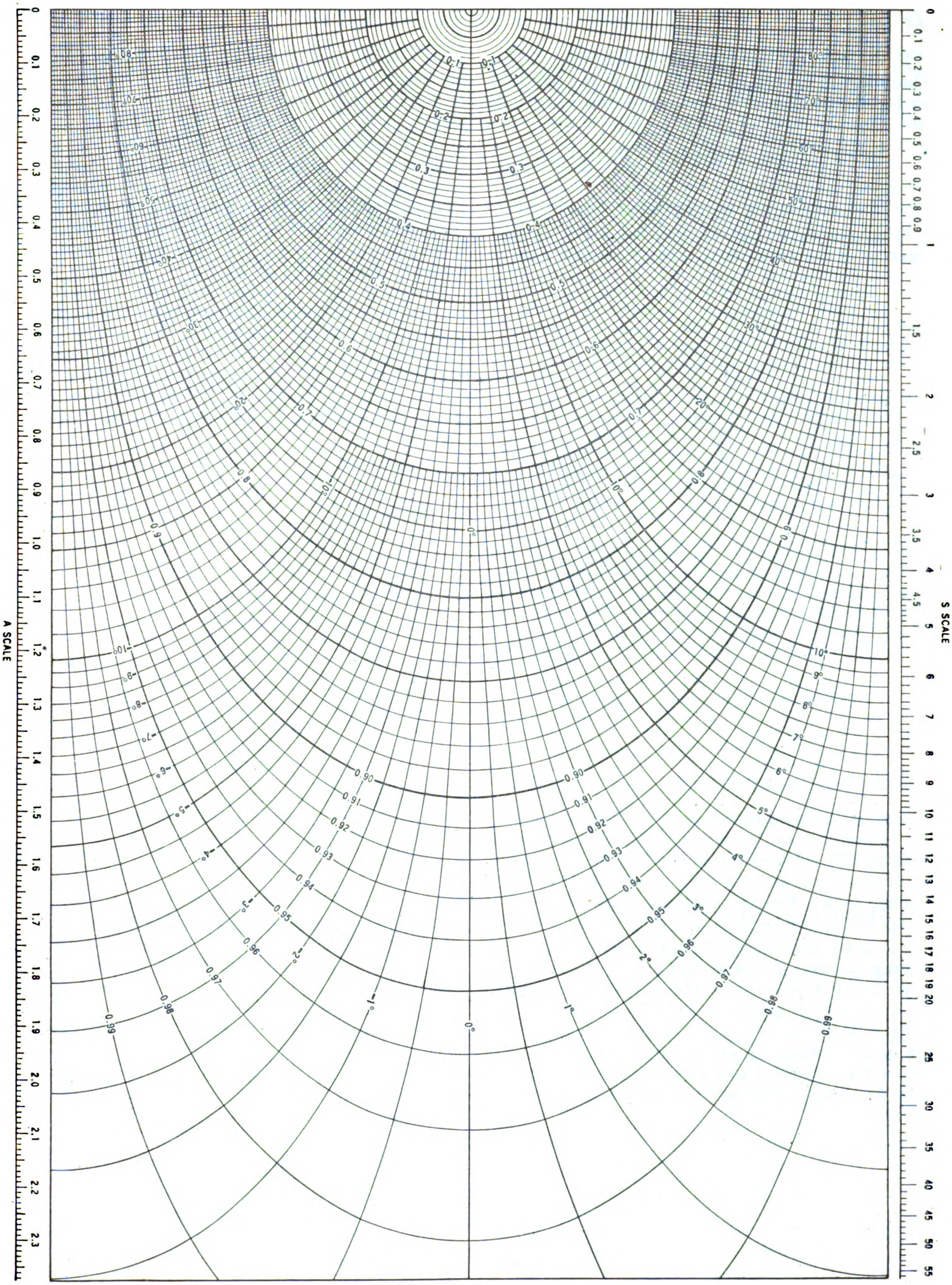
$$1/T = 0.494\,/\underline{78.2^\circ}$$

$$h = \frac{s}{\cos\phi} = \frac{0.16}{\cos 78.2^\circ} = 0.784$$

then by equation **11**,

$$e = e_o\sqrt{\frac{h\,t}{2}} = 60{,}000\sqrt{\frac{0.784}{2 \times 0.494}} = 53{,}500 \text{ volts}$$

$$I = \frac{E}{N\,T} = \frac{53{,}500 \times 0.494\,/\underline{78.2^\circ}}{382.5\,/\underline{-10^\circ}} = 69\,/\underline{88.2^\circ} \text{ amperes, charging current.}$$



Tangent Chart

If we wish the sending end impedance with the distant end of the line grounded, $T_o = 0$, the graphical part of the solution is the same as for the distant end free, with the result, $T = 0.494 \angle 78.2°$

$$E/I = N\,T = 382.5 \angle -10° \times 0.494 \angle 78.2°$$
$$= 189 \angle 68.2° \text{ ohms}$$

Construction of the Work Chart

Either one of two methods may be used in the construction of the work chart. First, the curves may be

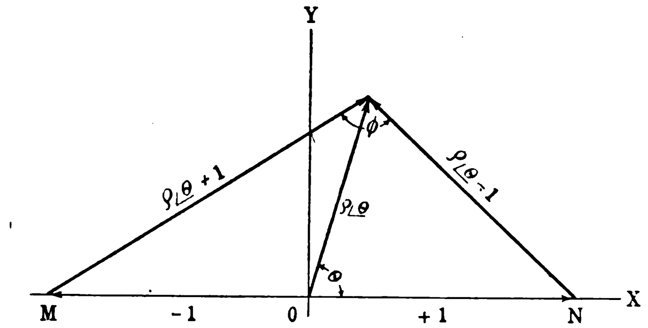


Fig. 10

plotted from their scalar equations, **8** and **9**, in the ordinary way, using tables of the hyperbolic functions and circular functions. Second, the curves may be plotted graphically, using an auxiliary diagram. This method does not require the use of either hyperbolic or circular functions. It is explained as follows.

$$T = \tanh W = \frac{\sigma^{W} - \sigma^{-W}}{\sigma^{W} + \sigma^{-W}} = \frac{\sigma^{2W} - 1}{\sigma^{2W} + 1}$$

Let $\sigma^{2W} = \rho \angle \theta$, then,

$$T = \frac{\rho \angle \theta - 1}{\rho \angle \theta + 1} = t \angle \phi$$

A vector diagram of this equation is shown in Fig. 10. From it may be seen that if we construct a triangle with a base two units in length, the ratio of whose sides is t, and the angle at whose vertex is ϕ, the line drawn from the midpoint of the base to the vertex will be the vector $\rho \angle \theta$. If ϕ is kept constant and t varied, the terminus of ρ will trace out a circle passing through M and N and having its center on $O\,Y$. If t is kept constant and ϕ varied, ρ will trace out another circle having its center on $O\,X$.

Here, then, we have another Argand diagram of orthogonal curves, Fig. 11, in which all the curves are circles and may be drawn with a compass. On such a diagram the A line would appear as a logarithmic spiral.

The connecting link between the circle diagram and the tangent diagram is the relation,

$$\rho \angle \theta = \sigma^{2W} = \sigma^{2u + 2jv}$$

from which,

$$\log \rho = 2\,u \qquad \text{and} \qquad \theta = 2\,v$$

We may thus derive the tangent diagram from the circle diagram, which is relatively easy to construct. That part of the circle diagram which is needed to construct the top half of the tangent chart is included in the segment $A\,B\,N\,D$. This area converts into the rectangle of the chart.

After the circle diagram is drawn a scale of $2\,u = \log \rho$ is accurately constructed by the aid of a table of logarithms. This scale is then laid on the circle diagram with its end at O, the value of $2\,u$ read from the scale, and the corresponding value of $2\,v$ read by means of a protractor. The resulting numbers, plotted in rectangular coordinates, yield the tangent chart.

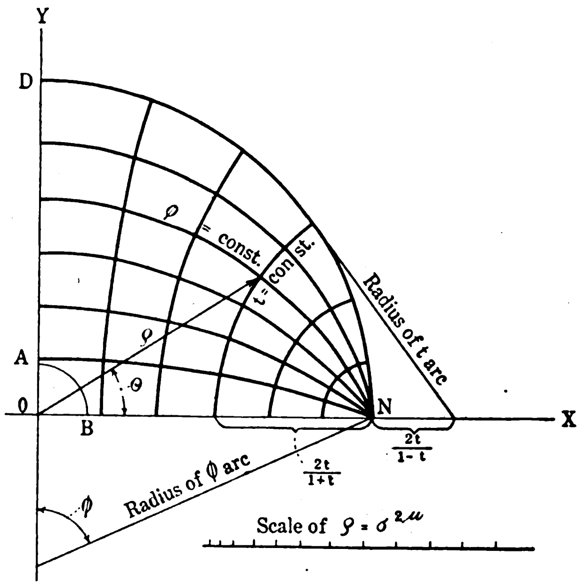


Fig. 11

Conclusion

It is hoped that the foregoing brief description of the tangent chart will interest others in this method with the result that means will be devised for using it in solving transmission line problems of even greater variety than those mentioned.

In conclusion the writer desires to express his sincere thanks to Messrs. Latour and Viard for their very excellent article on this method and to Dr. C. O. Mailloux for advice and suggestions in reference to the preparation of this paper.

JOURNAL OF THE American Institute of Electrical Engineers

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. NOVEMBER MEETING

The 372nd meeting of the Institute will be held on Thursday, November 17, 1921, in the Engineering Societies Building, 33 West 39th Street, New York, N. Y.

The afternoon meeting at 2 p. m., will be a joint session with the Society of Naval Architects and Marine Engineers, forming a part of the annual meeting of that society. The subjects of the session, Electric Auxiliaries, and Electric Propulsion of Ships, should prove of particular interest at this time when competition is growing so keen with the highly efficient ships being put into service by other nations. The two papers to be presented are as follows:

"Electric Auxiliaries on Merchant Ships," by E. D. Dickinson, Marine Department of the General Electric Company.

"Electric Propulsion of Ships," by W. E. Thau, Commercial Engineer of the Westinghouse Electric and Manufacturing Company.

There will also be an evening session of the Institute at 8.15 p. m., which members of the Society of Naval Architects and Marine Engineers and all others interested are cordially invited to attend. This session will be devoted to a lecture on "World Communication," by Alfred N. Goldsmith, Professor of Electrical Engineering, College of the City of New York.

A. I. E. E. MIDWINTER CONVENTION

FEBRUARY 15-17, 1922

The 10th Midwinter convention of the Institute will be held in New York, February 15-17, 1922, in the Engineering Societies Building. This will be the first meeting in 1922 under the new policy adopted by the Board of Directors which prescribes four general meetings of the Institute each year including the annual convention.

While a definite program cannot be announced at this time, the Meetings and Papers Committee has in hand several papers which have been accepted and is prepared to consider for this program any further manuscripts which may be received prior to December 15th.

FUTURE SECTION MEETINGS

Akron.—November 18, 1921. Paper: "A Discussion of the Superpower Survey Report." Speaker: Mr. W. S. Murray, Consulting Engineer, New York City.

December 8, 1921. Papers: "Design and Construction of the Westport Generating Station" by Mr. A. S. Loizeaux, Electrical Engineer, Consolidated Gas Electric Light & Power Co.; "Operating Problems in the Westport Generating Station" by Mr. A. L. Penniman, Superintendent Steam Stations, Consolidated Gas Electric Light & Power Co. The meeting will be held in the Service Building at the Westport Generating Station and will be followed by an inspection trip through the station.

Atlanta.—November 30, 1921. Subject: "Waterwheels."

Kansas City.—November 25, 1921. Subject: "Diesel Engines." Speaker: Mr. C. E. Beck.

Lehigh Valley.—November 10, 1921. At Nazareth, Pa. Subject: "Electrification of Cement Mills."

Minnesota.—November 28, 1921. Subject: "Theory of the Vacuum Tube and its Engineering Applications." Speaker: C. M. Jansky, Jr.

New York.—On the evening of November 14, 1921, a New York Section Meeting of the Institute will be held in the Engineering Societies Building auditorium at 8 p.m. The subject for the evening will be "The Great Lakes—St. Lawrence Canal." This will be a joint meeting of the Metropolitan Sections of the A. S. C. E., the A. I. M. E., the A. S. M. E. and the A. I. E. E. Complete details will be issued to the section membership as soon as available.

Philadelphia.—November 14, 1921. Subject: "The One Best Way to do Work." Speaker: Mr. Frank Gilbreth.

Schenectady.—November 4, 1921. Entertainment and smoker.

November 18, 1921. Subject: "Energy." Speaker: David B. Rushmore.

December 2, 1921. Subject: "Superpower System." Speaker: W. S. Murray.

Toronto.—November 25, 1921. Subject: "Instruments and Measurements."

December 6, 1921. Subject: "Distribution Records and Overhead Distribution."

A. I. E. E. DIRECTORS MEETING

OCTOBER 14, 1921

The regular bi-monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, October 14, 1921, at 3:00 p.m.

There were present: President, Wm. McClellan, Philadelphia; Past-Presidents, A. W. Berresford, Milwaukee, Calvert Townley, New York; Vice-Presidents, W. A. Del Mar, New York, H. W. Eales, St. Louis, N. W. Storer, Pittsburgh, F. R. Ewart, Toronto; Managers, W. I. Slichter, L. F. Morehouse, E. B. Craft, New York, G. Faccioli, Pittsfield, F. D. Newbury, Pittsburgh, L. E. Imlay, Niagara Falls, Harold B. Smith, Worcester; Treasurer, George A. Hamilton, Elizabeth, N. J.; Secretary, F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $24,105.06, was ratified.

Upon recommendation of the Finance Committee, a budget covering the activities of the Institute for the appropriation year commencing October 1, 1921, was approved.

Upon the recommendation of the Finance Committee, the following resolutions were adopted, establishing a working capital fund for the Institute:

WHEREAS it is desirable to set aside each year a portion of the funds of the Institute as reserve capital, to be used only in certain contingencies, under the direction of the Board of Directors,

RESOLVED that a "Reserve Capital Fund" be established in the accounts of the Institute.

RESOLVED that the $10,000 par value United States Government bonds and the $15,000 par value Wilmington City bonds owned by the Institute be hereby set aside and constituted a "Reserve Capital Fund."

RESOLVED that the Finance Committee of the Institute be authorized to include in each annual budget five per cent (5%) of the income of the Institute to be deposited annually in the Reserve Capital Fund.

RESOLVED that the entire Reserve Capital Fund be subject to withdrawal, in whole or in part, only upon resolution of the Board of Directors, but that the interest upon the fund be deposited in the general funds of the Institute and used for current expenses.

A report was presented of a meeting of the Board of Examiners held September 30, 1921; and the actions taken at that meeting relative to applications for election and transfer were approved. Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 137 Students were ordered enrolled; 109 applicants were elected to the grade of Associate; 8 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 26 applicants were transferred to the grade of Member.

Reports of progress were presented by the Meetings and Papers, Publication, and Coordination Committees, with reference to the plans under way for meetings and publications for the coming year. The direction in which these committees are working was approved in principle by the Board, and further detailed reports will be presented later.

The Standards Committee presented a report including recommendations of a proposed reorganization of the committee. This report was referred to a special committee of five members to be appointed by the President with power to take all steps requisite to formulate definite recommendations to the Board.

In addition to these actions other matters relating to important activities and the general policy of the Institute were discussed; reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

JOINT RUBBER INSULATION COMMITTEE

The Joint Rubber Insulation Committee, whose well-known specification for 30 per cent Hevea rubber insulation is now almost universally used in the purchase of high grade rubber insulation, has gone out of existence after 10 years of service to the electrical industry.

On the 15th of July, a sub-committee of the Joint Rubber Insulation Committee passed the following resolutions:

WHEREAS, the Joint Rubber Insulation Committee has completed its essential work, and

WHEREAS, its members are no longer in a position to continue its activities, and

WHEREAS, the American Engineering Standards Committee is now the recognized organization for the control of engineering standards, and

WHEREAS, the Constitution of the American Engineering Standards Committee requires that engineering standardization be brought within the influence of that committee through the recognized technical society, such as the American Society for Testing Materials, therefore be it

RESOLVED, that the American Society for Testing Materials be requested to assume responsibility for this work, and be it

RESOLVED, that should the American Society for Testing Materials accept this invitation it be requested to add to the membership of the committee, to which this work will be assigned, a suitable number of members of the Joint Rubber Insulation Committee to insure continuity of efforts, and be it

RESOLVED, that if this consolidation is effected, the Joint Rubber Insulation Committee shall go out of existence and the Secretary shall give due notice to the Technical Press, to the members of the Committee, and others especially interested.

The American Society for Testing Materials acted favorably upon the requests contained in these resolutions at a meeting of its executive committee held October 11th, 1921. The work of the Joint Rubber Insulation Committee will be taken over by committee D-11 on Rubber Products, the chairman of which is Mr. F. M. Farmer, and the Secretary, Mr. C. B. Martin, 466 Lexington Avenue, New York City.

The history of the work of the Joint Rubber Insulation Committee will be found in the report which was printed in the PROCEEDINGS of the American Institute of Electrical Engineers, April 1917, and the *Journal of Industrial and Chemical Engineering*, March 1917. Reprints of the report may be purchased from John Wiley & Sons, New York City. It contains a specification for rubber compound and the details of an analytical procedure which will determine the amount and quality of rubber.

DELEGATION OF AMERICAN ENGINEERS RETURNED FROM ABROAD

REPORT OF JOHN FRITZ MEDAL PRESENTATION CEREMONIES

The engineers forming the American delegation to England and France this summer were guests of honor at a welcome-home dinner given at the Pennsylvania Hotel, New York City, on the evening of October 10. Over two hundred engineers, representing American engineering societies, were present to extend greetings to the delegates. This delegation consisted of Ambrose Swasey, chairman; Charles F. Rand, secretary; Chas. T. Main, Robert A. Cummings and John R. Freeman, representing the American Society of Civil Engineers; Col. Arthur S. Dwight, Wm. D. Kelly and Mr. Rand representing the American Institute of Mining and Metallurgical Engineers; Dr. Ira Hollis, Jesse M. Smith and Mr. Swasey representing the American Society of Mechanical Engineers; and Dr. F. B. Jewett, Dr. A. E. Kennelly and Major General G. O. Squier representing the American Institute of Electrical Engineers.

Mr. J. Vipond Davies, president of the United Engineering Societies, was presiding officer, and in his opening remarks he stated the purpose of the gathering as "primarily to extend greetings to our delegation, but, looking beyond this immediate purpose, there is the greater and broader purpose for which these gentlemen went abroad and to which they have accomplished much, and that is the promotion of international comity and the closer professional relations between our peoples. In honoring our friends, we honor our profession in the broadest sense of a unified world-wide profession of engineering, united in the interest of efficiency and progress."

As to the reasons for the visit abroad he enumerated three distinct contributary causes:

1. To afford British engineers an opportunity to discuss with engineers of this country the amalgamation of engineering societies along the lines of the United Engineering Society and more recently The Federated American Engineering Societies.
2. To show appreciation of the great work done by engineers of England and France in the war.
3. To present John Fritz Medals to Sir Robert Hadfield, of England, and Eugene Schneider, of France.

Before introducing the speakers of the evening Mr. Davies read telegrams and messages received from the recipients of the medals, Mr. Hoover, the Institution of Civil Engineers, of London, the Institutions of Mining and Metallurgy and Mining Engineers, Capt. R. E. Sankey and Magnus Mowett, president and secretary, respectively, of the Institution of Mechanical Engineers, the British Iron and Steel Institute, Societe des Ingenieurs Civils de France, the Engineers Club of London, the Faraday Society, Viscount Bryce, Arthur Neal, member of Parliament from Sheffield, and finally messages from two of the members of the delegation who have remained abroad, Mr. Smith and Dr. Kennelly.

The one from Mr. Jesse Merrick Smith:

The coming together of engineers of all specialties and organizations under such pleasant auspices will greatly advance the profession as a whole.

From Dr. A. E. Kennelly:

May I be counted as if present with you at the dinner although 6000 kilometers distant. I feel assured that the delegation's visit to Paris is very appreciatively remembered here by our French confreres.

The first speaker of the evening was Consul General of Great Britain, Captain G. H. Armstrong. He felt it to be a responsibility of engineers of United States, England and France to draw close together to promote international friendship between these three countries and to assist in restoring happiness and regaining prosperity.

Ambrose Swasey, chairman of the delegation, was next introduced as "Dean of the Engineering Profession." Speaking of the engineers with whom the delegation came in contact while abroad Mr. Swasey said, "Their ideas and their problems as engineers are the same as ours; our problems are theirs. Therefore, we felt that the nearer we could get together, the better it would be for us all." He enlarged upon this thought when, after giving as his general impression that both England and France are well on their way toward a return to normal conditions, he said, in conclusion: "Those countries are near to us; they are nearer to us than ever. Their success means our success; and anything that we can do in bringing not only the engineers but the citizens of those great countries together, that we can join with them in all these great movements for good and righteousness, it will be that much better for the civilization of today."

The secretary, both of the delegation and of the John Fritz Medal Board of Award, Mr. Rand, outlined the experiences of the delegation in London. These included formal and informal functions—luncheons, dinners and receptions—a visit to the National Physical Laboratory, the presentation of the medal to Sir Robert Hadfield, and meetings with the councils of the institution of Mechanical Engineers and the Royal Society. All these events Mr. Rand described in a most entertaining manner. He also spoke of the honors conferred upon members of the delegation by various institutions.

Dr. Jewett, who arrived in London some two months in advance of the other members of the delegation, spoke of the preliminary work connected with their visit, all of which was done with the thought that the event was more than a meeting of engineers and exchange of felicitations between the engineering professions of America and Great Britain. In his association with engineers of Great Britain during this time Dr. Jewett was impressed first by the fact that the leaders in their engineering societies are older men than those leading the activities of the societies of this country and, secondly, by the greater degree of formality observed in the conduct of their engineering meetings.

Two members of the delegation, Mr. Cummings and Mr. Freeman, were able to accept the invitation of the National Society of Engineers of France to go with members of the Society on their annual excursion to the region of the French Alps. Mr. Freeman gave an account of this trip, the object of which was to see the recent developments in the southeastern part of France. Among the developments on which Mr. Freeman commented were those in metallurgy and hydroelectric power in the French Alps, and the new harbor works at Marseilles.

A general description of the visit of the delegation to France was given by Colonel Dwight. The initial gathering was held in the Eiffel Tower where a luncheon was served and brief addresses made. The John Fritz medal was presented to M. Schneider at an evening session of the Societe des Ingenieurs Civils. Later in the month a large part of the deputation met again at the works of Schneider and Company at Le Creusot. Colonel Dwight described briefly this plant, which is the largest and most important of the Schneider works, and the various social functions which took place. He spoke highly of the wonderful esprit de corps found in the Schneider plants which is the result of the care which the company has taken to develop an intelligent and enlightened system of industrial welfare work. Colonel Dwight, who served through the entire period of the war overseas, found marvelous progress in the work of reconstruction since the armistice and praised the wonderful spirit of the people of France which "in thousands of quiet ways is working out a solution of the perplexing problems of peace."

M. Gaston Liebert, consul general of the French Republic, addressed the meeting expressing appreciation of the cooperation and assistance of engineers in this country during the war and summarizing the problems of the French people and the ways in which these problems are being met. He then presented medals which at the request of M. Schneider and in the name of the French Republic, had been struck off for the following engineers:

Mr. Ambrose Swasey, general chairman of the delegation
Mr. Chas. T. Main, chairman, A. S. C. E. delegation
Dr. Ira N. Hollis, chairman, A. S. M. E. delegation
Col. A. S. Dwight, chairman, A. I. M. E. delegation
Dr. F. B. Jewett, chairman, A. I. E. E. delegation
Mr. Geo. S. Webster, president A. S. C. E.
Mr. Edwin Ludlow, president A. I. M. E.
Mr. E. S. Carman, president A. S. M. E.
Dr. W. McClellan, president A. I. E. E.

Following this ceremony Mr. George Clapperton, representing the Institution of Electrical Engineers in London, spoke briefly of the growth of that institution and its desire to work together with engineering bodies of other countries "in softening asperities and leading to that condition of respect, confidence, and esteem between peoples on which rests the hope of mankind."

The final speaker of the evening was Professor Jacques Cavalier, exchange professor from France, who endorsed the idea of the union between the engineers of various countries but emphasized the difficulty resulting from different languages. He believes that the exchange professorship movement may materially contribute to the union of the engineers of the two countries:

The meeting was closed with the announcement of honorary membership conferred upon Mr. Swasey and Mr. Kelly by the Institution of Mining Engineers.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorites is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—John A. Dickie, Hotel Washburn, Waukegan, Ill.
2.—Roy L. Ehmann, 4636 North St. Louis Ave., Chicago, Ill.
3.—Wm. J. Epps, Rua Dom Geraldo 80, Rio de Janiero, Brazil, S. A.
4.—G. Foung, Kay Sang & Co., 843 Clay St., SanFrancisco, Cal.
5.—H. L. Francis, F. C. Central Domincano, Puerto Plata, Dominican Republic.
6.—T. J. Hodge, 612 West 137th St., New York, N. Y.
7.—Conrad Jacobson, Hood River, Ore.
8.—Hugo Wm. Jacobson, 1402 East 63rd St., Chicago, Ill.
9.—Howard W. Key, Russell Mfg. Co., 60 East Forsyth St., Atlanta, Ga.
10.—Louis Kunser, Westinghouse Elec Mfg. Co. Swbd. Engg. Dept. K-90, East Pittsburgh, Pa.
11.—G. H. Lindsey, Rosemere Apts., 2255 West 14th St., Los Angeles, Calif.
12.—Chas C. Long, 1109 Arizona Ave., El Paso, Texas.
13.—Geo. C. McCabe, 137 West 86th St., New York, N. Y.
14.—Harry P. Meyer, 327 East 61st St., Los Angeles, Calif.
15.—Chas. Schindler, Great Western Power Co., Crockett, Calif.
16.—D. V. Stoute, 1946 Mosher St., Baltimore, Md.
17.—Frank N. Tucker, 551 East 40th St., Chicago, Ill.
18.—T. S. Young, Yonkers Y. M. C. A., Yonkers, N. Y.

AMERICAN ENGINEERING COUNCIL

SEPTEMBER MEETING

M. E. Cooley Elected President

Mortimer Elwyn Cooley, dean of the College of Engineering and Architecture of the University of Michigan, has been elected president of the American Engineering Council of the Federated American Engineering Societies, it was announced at the meeting of the Executive Board of the Council, held in Washington on September 30, 1921. Dean Cooley assumed office at once.

Mr. Cooley, a past-president of the American Society of Mechanical Engineers, is well-known in the engineering field. He was born in Canandaigua, N. Y., March 28, 1856, and was graduated from the United States Naval Academy in 1878. In 1881 he was detailed to the University of Michigan for three years, under a law which permitted the Secretary of the Navy to detail engineer officers as professors of "Steam Engineering and Iron Shipbuilding," and thus began his long connection with the university covering a period of nearly forty years. After the three years were ended a year's extension of his time was secured; but in 1885 he was ordered to the Pacific Station for duty, whereupon he resigned from the Navy to accept the chair of mechanical engineering at the university. The university also conferred upon him the honorary degree of M. E. He became dean of the College of Engineering in February, 1904, and of the College of Architecture in 1913. He received the degree of LL. D. from the Michigan Agricultural College in 1907; and the degree of Eng. D. from the University of Nebraska in 1911.

During the Spanish War, Dean Cooley served as chief engineer of the *Yosemite*, a converted Morgan liner manned by Michigan State Naval Militia. For a time following the war he was attached to the League Island Navy Yard, first as chief engineer in charge of the machinery of a number of ships and then as assistant chief engineer of the yard.

Mr. Cooley returned to the university in 1899 and during the years following undertook a large amount of important appraisal work, including investigation of the 10,000 miles of Michigan railways valued at $200,000,000, as well as telegraph and telephone lines, plank roads and river improvements. He has been foremost in many lines of public works, serving at various times on committees, such as the Engineering Committee at the Chicago Exposition and the Committee of Awards at the Pan-American Exposition. For sixteen years, 1895 to 1911, he was senior engineer officer of the Michigan State Naval Militia.

Besides being active in the work of the American Society of Mechanical Engineers, of which he was president during 1918-1919, Mr. Cooley has been vice-president of the American Association for the Advancement of Science; director of the American Society of Civil Engineers; vice-president of the Society for the Promotion of Engineering Education; and president of the Michigan Engineering Society.

Mr. Cooley plans to carry out an extensive program in the interest of the public and the profession of engineering with his new and larger opportunity as president of the American Engineering Council.

Progress of the Council's Work

Much important business was transacted by the Executive Board at the Washington meeting. The presiding officers were Calvert W. Townley and J. Parke Channing of New York, vice-presidents.

Department of Public Works. Progress was reported in the direction of establishing a Department of Public Works.

Patents. The Council adopted the report of the Committee on Patents, urging the passage of the Lampert Patent Office Bill to remedy conditions in the Patent Office. A resolution was approved expressing the conviction that this bill "provides the least increases in force and salaries which can possibly stop the retrogression of the Patent Office and enable it to make progress toward recovering an efficient condition, and by increases in the fees for patents, supplies the funds necessary to enable the Patent Office to continue to be self-supporting."

The committee opposed the passage of the Stanley Senate Bill which provides for an amendment to the Patent Act, requiring that patents to aliens be granted with a condition that unless such patents be worked in this country within two years after the granting of the patents, the government may grant licenses under them.

Employment. The report of the special Committee on Employment was discussed at length, resulting in the adoption of the following resolutions:

RESOLVED: That the Executive Board of the American Engineering Council endorses in principle a paid employment service but in the reduced fees to members of organizations supporting said service, and be it further

RESOLVED: That a Committee of five members of the Executive Board be appointed by the chairman and that the Boards of Direction of the four founder societies be requested each to appoint a member of its board in order to form a Joint Committee of the nine members on Engineering Employment in the power to organize an Employment Bureau, on a plan which will invite the cooperation of interested organizations.

Government Contracts. On this question the board made several important recommendations, covering the class of contracts, terms of payment, etc.

Classification of Engineers. The board endorsed the work of the committee on this subject. The chairman of the committee was authorized to appoint a sub-committee to make a comparative study of such proposed legislation as the Lehlbach and Smoot bills in order to present to the Council a final report and recommendation for action.

Annual Meeting in January. The Annual Meeting of the Council will be held in Washington in January. It was decided not to hold an engineering assembly at that time, in view of the business depression.

State Administrative Committee. The organization of a State Administrative Committee in such states as may seem necessary was authorized, in order to secure prompt action in any activity of the Federation.

Other Matters. Two applications for membership were approved, the new members being the Vermont Engineers Society and the Associated Engineers of Spokane.

The resignation of A. C. Oliphant as assistant secretary was announced. Mr. Oliphant is to become associated with M. O. Leighton and Company, consulting engineers of Washington.

The board received the report of Col. A. S. Dwight, the Federation's representative on the deputation which went abroad to confer the John Fritz Medal on Sir Robert Hadfield and Eugene Schneider. British engineers, he stated, manifested an active interest in the Federation, and steps have already been taken to organize the engineers of the British Empire along the same lines.

INDUSTRIAL WASTE

By L. W. WALLACE
Executive Secretary, F. A. E. S.

At the meeting of the Executive Board of the Federated American Engineering Societies held immediately after the organization meeting in Washington in November, 1920, Mr. Hoover suggested the formation of a committee to investigate industrial waste. The Executive Board at once authorized Mr.

Hoover to form such a committee. Late in December a small committee of four or five engineers was brought together by Mr. Hoover. This small committee selected the remaining members of what came to be known as the Committee on Elimination of Waste in Industry. This Committee finally was composed of eighteen engineers, Mr. Hoover being one of them.

In selecting the members of the committee care was taken to secure men of broad experience, clear concepts, and unbiased attitude towards industrial problems. Representatives of managerial, consultant, educational and editorial activities were chosen. The men also were selected so as to be representative of varied industrial activities and contacts.

Early in January the committee met in New York and outlined the policies to be pursued in making investigation of waste in industry. The essence of the plan adopted was to gather quickly such information as might be used to stimulate action and to lay the foundation for other studies. It was believed that a limited yet careful study would not impair the value of the facts disclosed or the significance of the recommendations based upon the same. The point of view of the committee was that its investigation might be compared to that of the preliminary designs of a mechanical engineer, or the work of a reconnoitering part of civil engineers or that of an assay of mining engineers. That is, in all of these matters the chief purpose was to obtain quickly investigation of conditions and of their trend with the idea in mind of making a more detailed and exhaustive work afterwards. So within less than five months the committee completed an assay or analysis of waste in six typical branches in industries and presented a summary of its findings to the Executive Board of American Engineering Council on June 3, 1921 at St. Louis. At that time a condensed news abstract was given to the press. Since that time releases have been made to the daily and technical press covering particular features of the report. In the meantime all of the material has been carefully edited preparatory to printing in book form. The book was scheduled to be ready for distribution on October 29th. The McGraw-Hill Book Company of New York is acting as publisher and distributor for the committee.

The original plan contemplated ten investigations in the field, including transportation and coal mining. Six have been completed. These include, the building trades, men's ready-made clothing, boots and shoes, printing, metal trades and textile manufacturing. In addition to these specific field studies, seven general reports of a statistical character were prepared, each of them dealing with some aspect of industrial waste or its elimination on an extensive or nation-wide basis.

The industries selected for specific study are of great public importance, for their operation directly affects the daily life of everyone. It is believed that the source of waste in these industries may safely be taken as generally characteristic of the whole waste in American industries. It is thought that the findings are not exceptional, and certainly the industries selected were chosen in the belief that they are fairly representative.

The Point of View. At no time did the committee desire to place the blame upon any individual, group or class. Its sole purpose was to endeavor to determine the factors through which waste is occurring and the probable causes for the same. It then desired to make recommendations that would lead to a reduction of the waste that is now occurring. It was believed that the waste occurring was the inevitable result of methods, practises or relationship in industry The committee has had relatively little interest in indicating the various responsibilities for such. In contrast it hoped to indicate the main opportunities for eliminating waste and to indicate what group or class had the greatest opportunity in adopting measures for such elimination.

No attempt has been made to define waste in the academic sense. In the committee's investigations industrial waste has been thought of as part of the material, time and human effort expended in production represented by the difference between average attainments on the one hand and the practical attainable performance on the other, as revealed by the detailed reports. In assaying waste in industry the committee has undertaken to evaluate this difference. This it has established no theoretical standard of performance or excellence but has developed a method of measurement to determine the degree of effective use of those factors within which it was believed waste might be discovered. It has conceived that a given practise is not wasteful until a better has been revealed.

Plan and Study—Questionnaire and Evaluation Sheet

The plan of study followed in each of these six branches of industry investigated was this: At the outset the members of the committee prepared an analysis of those factors and operations in the industry in which waste might be expected to be discovered, provided a comparison was made between average practise and the best known practise. From this analysis, a trial questionnaire was prepared to secure information and quantitative data to permit of comparing the record of one plant with another in the same industry. The questionnaire is composed of 58 main topics and 260 leading questions. This indicates the multiplicity of avenues through which waste may occur.

This trial questionnaire was then used in making a study of one plant in each industry. The results of these trial studies were then brought together, compared, reviewed by the committee and, as a result, a revised questionnaire and an evaluation sheet were prepared, to be used in making the studies upon which the report is based. The revised questionnaire, as used with suggested modifications based on the experience accumulated in its use in field studies, forms an important part of the report.

Calendar. Engineers and managers will be interested in the technique of the plans. One of the significant points was the dispatch with which the work has been organized, conducted and consummated.

The work actually began January 3, 1921. Five months later, June 3, the report was submitted to the Executive Board of the Federated American Engineering Societies. The report covers an assay of 6 industries, a special investigation of the health factors in industry, and a thorough search of all authoritative literature. The committee has also taken on a long-time study of continuous-process manufacture and has stimulated an intensive program for the training of industrial workers.

This extraordinary speed in execution was made possible through splendid cooperation on every hand. The fullest cooperation was obtained from management, labor, engineering and technical societies, public officials and from individual engineers, statisticians, economists, editors, and men in various walks of life. The committee made a practise, insofar as possible, to consult with every known agency, profession, or individual that could give any constructive assistance. At no time was there any pride of authorship. Furthermore, only a wealth of good humor, tolerance, team-play and unselfishness on the part of the committeemen, the field workers and the office force could have accomplished this task. As an evidence of unselfishness the work has been done at cost. The engineering firms that have made the field investigations have done so at cost. They have not charged anything for overhead or profit but have only requested that they be reimbursed for the actual salaries of the men in the field and their traveling expenses. The heads of these firms have spent many days on the work without compensation. Had the committee paid for the service which has kept 40 or 50 engineers in the field for approximately two months, at the ordinary rates for such professional service, the cost would have been many times larger. This remarkable demonstration of speed of execution, tolerance, unselfishness and of untiring efforts is worthy of this consideration given it. It within itself is indicative of what may be done in the elimination of waste in industry through having a definite purpose; careful plans; prescribed schedule; abundant tolerance; unselfish motives; a willingness to do.

Outstanding Features of the Report

Some of the outstanding features are:

First. There is a lack of common terminology and personnel factors. In a very marked degree engineers and factory managers do not speak a common language. The result is confusion. To one group the works manager means one thing, to another an entirely different meaning is conveyed. The public is likewise confused because it has not a common knowledge of the meaning of industrial terms. Take "Collective Bargaining" and "Closed and Open Shop" for examples. It is doubtless true that if people were asked to define or interpret such terms no approximate uniformity would be obtained in reply. The establishment of a common terminology and a clearer definition of industrial words and phrases would lead to the elimination of much misunderstanding throughout industry and therefore to a far greater degree of cooperation.

Second. There is a very great need for the establishment of standard units of measurement for the various factors of management. There are some factors of management for which it would be exceedingly difficult, if not almost impossible, to apply units of measurement, and yet there are many for which it has been done. There has been some progress in the way of establishing standards for gaging individual and group performance, but in a very large degree the practise is limited and it is based on inadequate data and faulty premises. Because scientific method has not been applied, the wage payment accounts for much of the loss. This is likewise true as to standards of performance. Few really know what is reasonable to expect in the way of output.

Third. One of the astounding findings was the disclosure that no agency can furnish complete, timely and authoritative information pertaining to one or all of the essential elements of production. When this is recognized it is not surprising that there have been so many irrational attempts to remedy some of the industrial, economic, social and political problems. Until basic, timely and authoritative data are known no rational remedy can be made to solve such problems as have characterized American industry in recent years. This has been very apparent in connection with unemployment. Even governmental agencies do not agree on this vital question. There is very great need for the establishment of complete, timely and authoritative sources of information pertaining to many of the vital questions involved in the operation of the complex industrial activity of this country.

Fourth. Another interesting and significant finding was lack in several industries of proper agencies whereby there may be a free exchange of information. Many important plants in industry have developed and perfected plans which are not known to the public in general. If such were known in detail the entire industry would be benefited. It is also true that there is a large amount of duplication of expenditure of money in research and for other purposes because of lack of exchange of information. There is a real need for some form of cooperation that will safeguard the interest of the public, yet will permit of a free exchange of information between organizations of a given industry and independent industries. The trade associations properly organized and managed can be an instrument of great usefulness. They should be encouraged after means have been developed whereby the interests of the public may be fully protected.

Fifth. The information gathered through investigation of the committee discloses that there is not as large an amount of waste from labor disputes as generally thought. This, however, is not to be taken to mean that the loss is not material, for it is. It is also true that labor disputes are a serious menace not only to the particular plant or industry but to dependent industries and to the public. The reason why the losses from labor disputes are not as large as commonly thought is perhaps due to the fact that disputes occur in seasonal industries. The loss of production brought about by the strike is frequently made up by the extension of an active period.

Sixth. Another significant finding was that there were no adequate functioning bodies for adjustment of industrial disputes and checking of their waste. Many attempts have been made through legislation to set up legal machinery for adjusting labor disputes. In a number of the states such authorized agencies have not functioned. Twenty-seven states adopted laws creating special State Boards or Commissions for settlement of labor disputes, but it has been only in Kansas that such a Board has functioned to any material extent. The Kansas Court of Industrial Relations has broad powers and has been active, but it has been in existence for too brief a period to draw any rash conclusion as to its effectiveness.

Seventh. One of the outstanding conditions that contributes to industrial waste is the lack of a rational standardization of methods, practises, policies and designs. There is no phase of industry where there is not an almost unlimited opportunity for reducing waste by greater standardization. This can be accomplished without curtailing the individuality.

Eight. Forty-two million men and women employed in the United States lose on the average of six days annually from illness, including non-industrial accidents. There are more than 5,000,000 workers with organic diseases resulting mostly from infection. There are more than 25,000,000 with defective vision requiring correction and it has been found in a number of plants that the increased quantity and quality of production resulting from correcting defective vision has more than paid for the cost of such correction. A great economic waste is occurring through subnormal standards of health and vigor.

Ninth. In 1919 there occurred in industry about 23,000 fatal accidents and about 575,000 non-fatal accidents causing four weeks or more of disability. Statistics show and authorities agree that at least 75 per cent of the accidents in industry can be prevented by the application of proved methods and policies. It is said that in the building industry alone by the adoption of proper methods the waste due to accident may be reduced from 75 to 80 per cent in from two to five years.

Tenth. The lack of industrial research in many industries is the cause for a large industrial waste. American industry has not made adequate use of this important tool in its productive efforts. One of the great needs is the adoption of industrial research as a common agency to bring about economic production.

The report of the committee gives many other interesting and important findings. The detailed information contained in the reports of the engineers that made a study of a specific industry discloses many avenues through which waste is occurring and points out what may be done in a practical way to prevent such large occurrence. The report also makes specific recommendations as to what management, labor and the public may do in the campaign against waste in industry. A study of the report makes it evident that no one escapes responsibility and that every one has an opportunity. In making the investigation and the report the committee desired to stimulate a study of this important matter and to cause all concerned to realize their opportunity. This was one of the important aims and purposes of the entire effort. It is gratifying to know that in part this purpose has been realized, as already evidence of action stimulated by the report has been apparent. A number of leading engineering organizations have given and will give special attention to the findings of the committee. The report has been and will be the basis for many serious discussions. Chambers of Commerce have also taken up the report in their meetings. In almost every instance where this has been done the engineers in the community have been invited in. Another large and important group is to give consideration to the report on the industry in which it is interested at a meeting to be held soon. This organization has invited the engineer that made the study in that particular industry to assist them in devising

means whereby recommendations pertaining to that industry may be put into action. One of the significant outgrowths of the work of the committee is that an engineer who made an investigation in a given industry has been invited in as arbitrator in a labor problem. They were so favorably impressed with the fairness of his findings that they unanimously invited him to act as arbitrator. The work of the committee has come to the attention of a number of important government officials and it has had some influence in certain governmental activities of recent days. It is earnestly hoped that many individuals and groups will give serious consideration to this important report to the end that the campaign for the elimination of waste in American industry may be conducted on a large scale in the months immediately ahead.

The elimination of waste in American industry is an important matter. If American industry is to flourish, if it is to pass successfully through the present crime period and if it is to be able to meet successfully foreign competition and at the same time offer opportunities for advancement to the American workman and to pay such compensation as not to lower the standards of living and retard individual desire of increase in the standards of living, there must be a material reduction in the economic waste that is now occurring.

PERSONAL MENTION

J. T. Travis has opened electrical engineering offices in the Rialto Building, Kansas City, Mo.

V. A. Zehr, consulting engineer of Pekin, Ill., returned on October 17 from a business trip to Europe.

R. I. Maujer is now branch manager of the Cincinnati office of the Cutler-Hammer Manufacturing Company.

C. A. Adams, who has been on part-time leave from his duties at Harvard University, has returned to the university to resume full-time teaching.

Percy A. Robbins, who until recently practised consulting engineering in San Francisco, has retired from active work, and will live in Highland Park, Ill.

Wm. Hamblin Cahoon has left Lockwood, Greene & Company, New York City, and is with Woodwell & Resler, of New York, as electrical engineer.

M. L. Pyle has resigned his position at Bridgeport, Ala., with the Public Light and Power Company, to enter the employ of the Kentucky Utilities Company.

H. P. Westervelt, until recently district manager for the Century Electric Company, Boston, is now with the New England Appliance Company, of Boston.

Edward W. Legier, formerly with the B. F. Goodrich Company, Akron, O., is now located with the American Blower Company, Chicago, as sales engineer.

Carl F. Hofstetter, formerly with the Wagner Electric Manufacturing Company of St. Louis, is located with The Mechanical Appliance Co., Milwaukee.

L. F. Woodruff has left the General Electric Company to become instructor in the electrical engineering department of the Massachusetts Institute of Technology.

Joseph A. Elzi has become instructor in the University of Colorado. He has been located with the Westinghouse Electric & Manufacturing Company of E. Pittsburgh.

Ivar Herlitz is with the Southern Sierras Power Company, Riverside, Cal. During the past year he was in the electrical laboratory of Union College, Schenectady, N. Y.

T. I. Dekle, with the Westinghouse Electric & Manufacturing Company since 1917, has left to enter the service of the Cline Electric Manufacturing Company, Chicago, as control engineer.

E. B. Snyder is with The Ohio Brass Company, Mansfield, Ohio, in the capacity of manager of high-tension sales. He was previously with the Ohio Insulator Company, Barberton, Ohio.

Ben H. Krey, formerly of the General Electric Co., has opened an office at 101 Park Ave., New York, as consulting electrical engineer.

Walter W. Johnson has left the Crete Mining Company, Hibbing, Minn., and is associated with the Pickands Mather Company, Duluth, as electrical engineer in the mining department.

Frank E. Overbey has left the Cutler-Hammer Manufacturing Company of New York to accept the position of assistant superintendent with the Bauer Electric Company of Hartford, Conn.

George R. O. Rutherfurd has become traffic engineer with the Southern California Telephone Company, Los Angeles. He was previously with the Pacific Telephone & Telegraph Company, Sacramento, Cal.

F. V. Armistead, who has been located in the Schenectady office of the General Electric Company, was recently transferred to the Charleston, W. Va., office, for sales work and engineering service in that vicinity.

Louis E. McCoy has been made assistant superintendent of the North Shore Power Company at Three Rivers, Que. Until recently he was engineer draftsman with the Shawinigan Engineering Company, Ltd., Montreal.

James Lynah, formerly president of the Domestic Labor Saving Corporation, New York, has become affiliated with O. A. Barnard in the firm of Barnard-Lynah, Inc., of New York. Mr. Lynah is vice-president of the firm.

Walter H. Weeks, formerly illuminating engineer with the General Electric Company in New York, has become sales engineer in the department of government and corporation sales with the Goodyear Tire & Rubber Company, New York.

Elbert R. Spencer has accepted the position of district manager of The Defiance Motor Truck Company, Defiance, Ohio. He was previously office manager of the Pittsburgh district office of the Allis-Chalmers Manufacturing Company.

HERBERT S. EVANS, who has been associated with the General Electric Company for twenty years, the past ten years as an executive in its foreign department, has left that company to become president of The "Bleh" Company of New York City.

C. R. ALDEN, formerly dean of the school of engineering, Institute of Technology, Detroit, has accepted appointment as dean of the college of engineering, Ohio Northern University, Ada, Ohio.

T. P. STRICKLAND has left the service of the New South Wales Government Railways and Tramways, to become chief engineer of the Melbourne and Metropolitan Tramway Board, Melbourne.

CHARLES P. TOWNSEND, JR., has accepted appointment as superintendent of the Abbeville Water & Electric Plant, Abbeville, S. C. He was previously with the General Electric Company in Atlanta, Ga.

B. B. BESSESEN has become an instructor in the electrical engineering department of Oregon Agricultural College, having left his position as sales engineer with the Manistee Iron Works, in Seattle.

GILBERT C. LAMB, formerly with The American Railways Company, Philadelphia, and the General Electric Company, Schenectady, has become associated with the engineering department of the Condit Electric & Manufacturing Company of So. Boston.

HOWARD H. ADAMS, who has been a cadet engineer with the United Improvement Company, Philadelphia, is now located with the Northern Indiana Gas & Electric Company, at Hammond, Ind., as assistant superintendent in the engineering department.

P. S. JONES, with the Cutler-Hammer Manufacturing Company, has been made branch manager of the Pittsburgh office. A. G. PIERCE, of Pittsburgh, continues as manager of the central district, comprising the Cleveland, Pittsburgh and Cincinnati offices and territory.

JAMES F. NEILD has become associated with the Toronto Transportation Commission, Toronto, Ont., in the capacity of electrical engineer. Mr. Neild was located until recently with the Toronto Railway Company, where he had been superintendent of substations for eight years.

HARRY W. EASTWOOD, who for the past four years has had charge of the Steel Mill and Crane Division of the Cutler-Hammer Manufacturing Company, Cleveland Branch, has been made branch manager, taking the place of Lynn B. Timmerman, who leaves to enter the automobile business in Lima, Ohio.

HENRY C. TOWNSEND announces that the practise of patent, trademark and copyright law heretofore carried on by himself and the late Mr. Charles F. Tischner under the firm name of Townsend & Decker, will be continued by himself and Mr. Frederick B. Townsend under the same firm name.

B. E. FERNOW, JR., has taken up work as instructor in Cornell University. Mr. Fernow was previously located with the Cutler-Hammer Manufacturing Company, Milwaukee, having been chief engineer of the magnet and clutch department since 1917. He is a graduate of Cornell University, and a Fellow of the INSTITUTE.

JOSEPH P. DANKO is now located in Hollywood, Cal., where he is owner of the B & M Electric Shop. Mr. Danko was for several years a radio engineer in the signal service of the War Department, until the past year, during which he was connected with the International Coal Products Corporation, at the Irvington, N. J., plant.

HARRY F. DART has severed his connections with the Rice Institute of Houston, Texas, to accept a position as instructor in the electrical engineering school of Harvard University. During a part of the summer season Mr. Dart was engaged by the International Correspondence Schools of Scranton, Pa., on text-book editing work.

H. S. FOLEY, who for the past four years has been the New York representative of the Compagnie Generale d'Electricite, of Paris, France, and its associated companies, has recently been appointed chief engineer of the Compania Hidroelectrica e Irrigadora del Chapala of Guadalajara, Mexico, and has now gone to that city to take up his new work.

WM. E. WICKENDEN has been transferred from the staff of the Western Electric Company to that of the American Telephone and Telegraph Company, where he will be assistant vice-president. Before entering the service of the Western Electric, Mr. Wickenden was assistant professor of electrical engineering in the Massachusetts Institute of Technology.

J. V. MONTGOMERY is now associated with the Westinghouse Electric and Manufacturing Company as general foreman of electrical construction at the Hell Gate station of the United Electric Light and Power Company, New York City. Mr. Montgomery was until recently an engineer in the electrical division of Dwight P. Robinson and Company, Inc.

NELSON S. MOORE has severed his connection with the Electric Power Equipment Corporation of Philadelphia, and has opened an office in Chicago, under the firm name of Nelson S. Moore & Company, for the purpose of acting as exclusive district representative for manufacturers of high-tension electrical apparatus, offering both engineering and sales service.

W. E. FREEMAN has been appointed acting dean in the College of Engineering of the University of Kentucky. For the past year Mr. Freeman has been supervisor of commercial training with the Westinghouse Electric & Manufacturing Company at East Pittsburgh, Pa., but previous to that time was head of the department of electrical engineering in the University of Kentucky.

J. G. ZIMMERMAN and A. L. SUDDUTH, of Milwaukee, Wis., have formed The Z-S Company, a partnership for research and development work, and for completing or perfecting inventions, especially in the line of ignition engineering. Mr. Zimmerman is instructor in ignition at the School of Engineering of Milwaukee and Mr. Sudduth is laboratory instructor in ignition at the same school.

J. G. KOPPEL, formerly electrical and mechanical engineer of the Sault Ste. Marie Bridge Company, Michigan, and lately construction engineer with the B. F. Goodrich Rubber Company, Akron, Ohio, having left that company on account of the de-

pression last fall, has been in Oregon since, and has recently organized the Eugene Machine & Auto Company, Eugene, Oregon, of which he is president.

D. McFarlan Moore has recently become a vice-president of the Illuminating Engineering Society. Mr. Moore has been well-known in electrical circles for a number of years, especially in connection with his vacuum-tube lighting system. He is at present manager of the Moore Light Department of the General Electric Company at Harrison, N. J. He is a Fellow of the Institute and has served in other technical bodies.

R. W. Stovel has recently joined with H. A. Brinkerhoff in the firm of Stovel & Brinkerhoff, engineers and constructors, New York City. Mr. Stovel is a graduate of McGill University, from which he received the degree of M. S. in 1900. He has had a wide experience in electrical and mechanical engineering, including a number of years with Westinghouse, Church, Kerr & Company, where he was managing engineer for some time. During the war he was with the A. E. F. as Lt. Colonel in charge of the mechanical and electrical equipment at all ports used by the American Army in France. Mr. Brinkerhoff is a mechanical engineer who has had responsible charge of many large engineering and construction undertakings.

OBITUARY

Dr. Emil A. Budde, prominent German scientist and electrical engineer, and an Honorary Member of the Institute since 1912, died recently at the age of 80. He was educated at the gymnasiums of Arnsberg and Dusseldorf and at the University of Bonn, where after graduation he became assistant in mathematics and physics. During the Franco-German war he was a war correspondent for the *Koln Zeitung*, later becoming editor and then foreign correspondent. In 1887 he opened a private laboratory in Berlin and in 1892 was appointed physicist with the Siemens & Halske Company, of which organization he was director from 1893 on, for many years. He contributed largely to German scientific publications and was the author of numerous books on physics, mechanics, philosophy, etc. Dr. Budde was official delegate for Germany with Helmholtz at the Chicago International Electrical Congress in 1893. He was one of the founders of the Verband Deutscher-Elec trotechniker of which he served as secretary and later president. He was president of the International Electrotechnical Commission succeeding Dr. Elihu Thomson.

Alexander M. Gray, professor and head of the electrical engineering department at Cornell University, died on October 13, 1921, after a prolonged illness. Prof. Gray was born in Edinburgh, Scotland, in 1882. He took the mechanical engineering course at Heriot Watt College, Edinburgh, and was awarded a diploma. He then entered Edinburgh University and was graduated with the degree of B. Sc. in Civil Engineering. In 1906 he completed the electrical engineering course at McGill University, Montreal, receiving the degree of B. Sc. He then spent three years as a designer of electrical machinery with the Bullock Electric Company, and two years as head of the a-c. motor department of the Allis-Chalmers Company. He left this work to become assistant professor of electrical engineering at McGill University and in 1915 accepted the position as head of the same department at Cornell. Prof. Gray was the author of several books on electrical machine design. During his connection with the Institute, of which he became an Associate in 1906 and a Member in 1913, he served upon the Educational, Electrical Machinery and Meetings & Papers Committees, and also the Committee on Student Branches.

Percy C. Henry, superintendent of distribution for the New England Power Company, was killed at the Worcester, Mass., substation on September 9, 1921. His death was caused accidentally during the demonstration of a device designed for the testing of pin-type insulators. Mr. H. B. Bush, of Cleveland, Ohio, inventor and demonstrator of the device, was also instantly killed. Mr. Henry had been with the New England Power Company for the past year. He was born in Bourbon, Ill., October 22, 1889, and was graduated from Purdue University, the first year and a half of his college work, however, having been done at the Massachusetts Institute of Technology. After some experience with the Commonwealth Edison Company of Chicago and the Illinois Steel Company in Gary, Ind., he became electrical superintendent of the Massena, N. Y., plant of the Aluminum Company of America, which position he left to become connected with the New England Power Company. Mr. Henry joined the Institute first as a student member, becoming an Associate in 1916.

Earl S. James, assistant superintendent of the electrical department of the Oklahoma Gas and Electric Company, died August 28, 1921. Mr. James had been with this company for fourteen years, starting as an apprentice in the electrical testing and repair department. Born in Bosworth, Mo., in 1891, he finished high school, and then took the I. C. S. course in electrical engineering. He became an Associate of the Institute in 1920.

Winthrop G. Bushnell died of heart disease at his home in New Haven, Conn., on October 23, 1921. Mr. Bushnell has been prominent in the development of public utilities, particularly in Connecticut, where he merged the New Milford Power Company and the Falls Village Water Power Company into the Connecticut Power Company, now supplying power to a large part of the state. He was also connected with the successful development of power projects in Cuba. He was director for the Delaware Aircraft Company. Mr. Bushnell was a graduate of Yale, 1888, and for many years was connected with the General Electric Company and its predecessors. His father, Cornelius S. Bushnell, financed the building of the *Monitor* of Civil War fame. Mr. Bushnell had been an Associate of the Institute since 1903.

Dr. Joseph W. Richards, professor of metallurgy at Lehigh University, died suddenly of heart disease at his home in Bethlehem, Pa., on October 10, 1921. Born in Oldburg, England, fifty-seven years ago, Dr. Richards come to this country as a boy and was educated here, attending Lehigh University. He began teaching at Lehigh in 1887. In 1902 he was active in the formation of the American Electrochemical Society, becoming its first president; and in many other ways has been active in his profession, being recognized as one of the foremost chemists in this country, and acquiring an international reputation as a metallurgist, especially known as an authority on aluminum. He was the author of many scientific works, and was one of the founders of *Electrochemical Industry*, the forerunner of *Chemical and Metallurgical Engineering.*

Albert C. Schweizer. Word has been received of the recent death of Albert C. Schweizer of the New York Edison Company. Mr. Schweizer started with this company when a boy, in 1894. His last position was that of deputy assistant superintendent in the office of the general superintendent of distributing stations, where his work pertaining to methods and systems of d-c. feeder distribution was considered remarkable; and the company felt that his untimely death at the age of 41 cut short a career of much promise. Mr. Schweizer was a graduate of Cooper Union which he attended while retaining his position with the New York Edison Company. He became an Associate of the Institute in 1920.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (Sept. 1-30, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

A. S. T. M. Standards, 1921.

Phila., American Society for Testing Materials. 890 pp., illus., 9 x 6 in., cloth. $10.00.

The 1921 volume of standards contains the specifications and methods of testing approved by the Society. These number 160, and have to do with a variety of materials—ferrous and non-ferrous metals, cement, lime, gypsum and clay products, preservative coatings, road materials, coal and coke, timber, timber preservatives, etc. Nearly one-half of the standards have been revised since the last edition appeared, or are new.

Alternating Currents.

By Carl Edward Magnusson. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 559 pp., illus., 9 x 6 in., cloth, $4.50.

A presentation of the fundamental principles of alternating-current phenomena, with illustrations of their application to industrial problems, intended to aid the student in gaining clear concepts of what actually takes place in alternating-current machinery, to explain the relations between the factors involved and to express the physical facts in mathematical forms in such a manner that he shall understand the equations and be able to use them rationally in the solution of industrial problems.

America's Power Resources.

By Chester G. Gilbert and Joseph E. Pogue. N. Y., The Century Co., 1921. 326 pp., illus., 8 x 5 in., cloth. $2.50.

An attempt to interpret the importance attaching to the energy resources, coal, oil, natural gas and waterpower, to point to the shortcomings in the way they are handled, to outline the changes in the administration of energy which are bound to come into play if due social and industrial progress is to be attained, and to indicate the avenues of advance along which constructive efforts should be applied.

The material presented is largely the result of investigations by the authors, brought out from time to time as special papers, emanating mostly from the Division of Mineral Technology, United States National Museum, and more popularly presented here in a unified and less technical form.

Analytic Geometry, with Introductory Chapter on the Calculus.

By Claude Irwin Palmer and William Charles Krathwohl. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 347 pp., 8 x 5 in., cloth. $2.50.

The object of this book is to present analytic geometry to the student in as natural and simple a manner as possible without losing mathematical rigor. It is based on the course given at the Armour Institute of Technology.

Automatic Telephony.

By Arthur Bessey Smith and Wilson Lee Campbell. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 430 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

The method adopted is to describe fully the typical circuits and apparatus of the Strowger type, and to outline briefly the other important systems. By this method it has been possible to explain the principles and methods fully enough for their application to other makes of equipment, without attempting to narrate the practise of all manufacturers in detail.

This edition is radically changed from the previous one, by the elimination of obsolete matter and the introduction of new material.

Concrete Work.

By William Kendrick Hatt and Walter C. Voss. Vol. 2. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 206 pp., illus., 8 x 5 in., cloth. $2.00.

The second volume of this practical text-book is a systematic course in the application of the fundamentals of concrete work, as set forth in volume one, to a series of representative examples. The complete work forms an unusually practical course in concrete construction.

A Dictionary of Applied Chemistry.

By Sir Edward Thorpe. Vol. 2. Revised and enlarged edition. Lond. and N. Y., Longmans, Green and Co., 1921. 717 pp., illus., 9 x 6 in., cloth. $20.00.

The second volume of this welcome revision of the standard reference work in English on applied chemistry to appear during 1921 carries the work to the subject of Explosion. Under the direction of Sir Edward Thrope, the work has been done by a long list of competent authorities, who have signed all the longer articles. The work, when complete, promises to be about one-third larger than before.

E. M. F. Electrical Year Book.

Edited by Frank H. Bernhard. First annual edition, 1921. Chicago, Electrical Trade Publishing Co. 1406 pp., illus., 12 x 9 in., cloth. $10.00.

A combined encyclopedia, dictionary and trade director of the electrical industry, prepared by a large editorial staff, and containing a great amount of up-to-date information of the kind most sought by those connected with electrical enterprises or using electricity. The volume is arranged alphabetically tnd is a convenient reference book on matters of theoretical, aechnical and industrial interest.

Electric Furnace.

By J. N. Pring. Lond. and N. Y., Longmans, Green & Co., 1921. (Monographs on industrial chemistry.) 485 pp., plates, illus., 9 x 6 in., cloth. $10.50.

Although the most noteworthy branches of the electrochemical and electrometallurgical industries have been described in a number of publications, the present rapid progress of these enterprises demands a frequent revision and extension of the literature. This volume is an additional contribution to the general technical discussion of the position and prospects of high-temperature industrial chemistry.

The author reviews the history and principles of the electric furnace and describes the types in use. Current supply, transformers and the measurement of high temperatures are treated and the use of the electric furnace in the metallurgy and chemistry of the [illegible] metals is described. Attention is also given to furnace design and to the economic aspects of electrochemical processes. [illegible] bibliography is appended.

ELEMENTS OF SPECIFICATION WRITING.

By Richard Shelton Kirby. Second edition, revised. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 153 pp., 9 x 6 in., cloth. $1.50.

This is a text-book on the art of specification writing, not a collection of specifications. It is based on the course given by the author in the Sheffield Scientific School of Yale University. The revision has been made with the purpose of modernizing the book and of making it more useful for those outside the profession of civil engineering.

A FIRST COURSE IN ANALYTICAL GEOMETRY.

By Charles N. Schmall. Second edition, enlarged. N. Y., D. Van Nostrand Co., 1921. 338 pp., 8 x 5 in., cloth. $2.25.

A course of moderate scope, designed for use in colleges and scientific schools, and as an introduction to advanced courses.

INDUCTION MOTOR AND OTHER ALTERNATING-CURRENT MOTORS

By B. A. Behrend. Second edition, revised and enlarged. N. Y. and Lond., McGraw-Hill Book Co., Inc. 1921. 272 pp., ports., diagrs., 9 x 6 in., cloth. $4.00.

This work appeared first in 1901 and is based on a series of lectures delivered at the University of Wisconsin during the preceding year. This second edition, twenty years later, has been expanded from 105 to 272 pages and thoroughly revised to represent the author's present opinions on its subject.

The book is not meant to be encyclopedic. It is, in the words of the author, "essentially the work of an engineer, who has had the good fortune to have been actively associated with the art of electrical engineering through almost three decades and who has had a part in the development of the machines about which he writes."

He thus addresses himself to his fellow-engineers, revealing the methods which he has followed in the design and construction of alternating-current motors, of which literally millions of horse power were executed under his direction.

POWER HOUSE DESIGN.

By Sir John F. C. Snell. Second edition. Lond. and N. Y., Longmans, Green & Co., 1921. (Electrical engineering series.) 535 pp., illus., diagrs., tables, 9 x 6 in., cloth. $14.00.

In preparing this book, the author has drawn upon his own experience of over twenty years and has collected and classified the experience of other engineers. The information thus acquired has been carefully sifted and condensed in the present volume, which the writer believes to contain all the requisite practical information on its subject. The principles and information given cover the design and equipment of central stations and isolated plants for supplying light and power to cities, factories, mines, railroads, etc., and are accompanied by typical examples of modern installations. This edition has been thoroughly revised and to a considerable extent rewritten.

PRACTICAL TRACK MAINTENANCE.

By Kenneth L. Van Auken. Second edition. Chicago, Railway Educational Press, Inc., 1921. 274 pp., illus., 8 x 5 in., cloth. $2.50.

Van Auken's book is designed to cover the essentials of routine section work, as approved by practical track men of varied experience. It is therefore adapted for use as a guide in the every day work of the foreman or supervisor. The second edition is apparently an unchanged reprint of the first.

THERMODYNAMICS.

By J. E. Emsweiler. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 266 pp., diagrs., 9 x 6 in., cloth. $3.00.

An attempt to present the subject progressively so that the reader may easily recognize the relation of each new demonstration to the whole. For this purpose the order of presentation is changed from that usually employed. Steam is placed first, followed by vapor refrigeration, after which the permanent gases, mixtures and air heat engines are studied. Formal discussion of the laws of thermodynamics and the kinetic theory of gases is postponed until the close of the book.

WHITTAKER'S ELECTRICAL ENGINEER'S POCKET-BOOK.

Edited by R. E. Neale. Fourth edition. Lond. and N. Y., Sir. Isaac Pitman & Sons, Ltd., 1920. 671 pp., illus., 6 x 4 in., [illegible]. $4.00.

This edition, the first in nine years, has been entirely rewritten. Its scope has been materially extended and the assistance of several specialists secured in order that the treatment of each subject might accord with the latest practise.

The book is intended, while covering the range of matter and having the convenience of reference commonly expected from a pocket-book, also to furnish an up-to-date synopsis of each subject which will have the coherency and wealth of detail usually found only in text-books, so that the volume may be equally useful for systematic reading and for reference. The field covered is broadly that of industrial electrical engineering.

YEAR BOOK OF THE AMERICAN BUREAU OF METAL STATISTICS.

First annual issue, 1920. 62 pp., tables, 10 x 8 in., paper.

This book, prepared under the direction of W. R. Ingalls, was designed to be a compilation of the statistics of the production, consumption and commercial movements of copper, lead and zinc in the principal countries of the world, covering, in general, the last ten years. The figures given are taken from the best available government and commercial sources, and great care has been taken to insure accuracy. The countries included are the United States, Great Britain, France, Belgium, Sweden, Italy and Japan.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—September 28, 1921. Paper: "Electric Arc Welding." Author: Mr. A. F. Davis, of the Lincoln Motor Company. Attendance 20.

Atlanta.—September 29, 1921, Chamber of Commerce Building. Subject: "Radio Telephony and Wireless Telegraphy." Speaker: Mr. H. E. Bussey, District Manager of the General Electric Company. Attendance 37.

Chicago.—October 3, 1921, Rooms of the Western Society of Engineers. Joint meeting with the Western Society of Engineers. Subject: "A Review of the Northwestern Elevator Explosion." Speaker: Mr. David J. Price, Engineer in Charge of Development Work, Bureau of Chemistry, U. S. Dept. of Agriculture. Attendance 270.

Cincinnati.—September 15, 1921, Literary Club Rooms. Joint meeting with the Engineers Club. Subject: "Radio Communication." Speaker: Professor S. M. Kintner, of the Radio Engineering Department of the Westinghouse Electric & Manufacturing Company. Attendance 150.

Connecticut.—September 21, 1921. The meeting was preceded by a visit to the principal Hartford Exchange of the S. N. E. Telephone Company, followed by a dinner at the Hartford Club. (1) Mr. E. H. Everit, Chief Engineer of the S. N. E. Telephone Company, explained the evolution of machine switching and gave interesting instances of the influence of the operator's psychology on the form taken by the mechanical equipment. (2) Mr. Samuel Ferguson, Vice-President of the Hartford Electric Light Company, analyzed the reports of the Hydroelectric Power Commission of Ontario for the purpose of decomposing the operating costs into elements associable with the remarkably low domestic rates in the Ontario towns. (3) Mr. R. W. Simpson, of the engineering staff of the Travelers Insurance Company of Hartford, emphasized the importance of safeguarding electrical equipment in industrial plants. (4) Mr. L. W. W. Morrow, delegate to the Salt Lake City Convention of the A. I. E. E., reported on the proceedings of the Convention. Attendance 80.

Detroit-Ann Arbor.—September 16, 1921, Detroit Board of Commerce. Joint meeting of all Detroit Technical Societies. The meeting was called for the purpose of organizing The Affiliated Technical Society of Detroit and discussing the proposed Constitution. Attendance 300.

Fort Wayne.—September 27, 1921, G. E. Club Rooms. (1) Mr. R. H. Chadwick, Chairman of the Section, talked briefly on the aims of the Section for the coming season, and asked for cooperation between all of the members and the officers. (2) Mr. J. J. Kline, delegate to the A. I. E. E. Salt Lake City Convention, described one of the trips taken by the delegates to the Utah Copper Company's mine. (3) Mr. Howard Miller, Chairman of the Meetings and Papers Committee, outlined the program for the coming year as far as it has been arranged. (4) Mr. P. M. Staehle, Chairman of the Membership Committee, spoke on the advantages of belonging to an association of engineers and urged all interested men to become members of the Section. The Entertainment Committee then took charge of the program, which included violin and vocal solos. Refreshments were served. Attendance 50.

Kansas City.—September 30, 1921, University Club. Appointment of Membership Committee, and report of Chairman Shaad on the A. I. E. E. Salt Lake City Convention. Speaker of the evening: Dean McCaustland, of the University of Missouri. Subject: "Duties an Engineer Owes to His Community." Attendance 19.

Lehigh Valley.—September 29, 1921, Hotel Allen, Allentown, Pa. Dinner followed by a meeting at which Mr. H. W. Smith, of the Westinghouse Electric & Manufacturing Company, E. Pittsburgh, presented an illustrated paper on the subject of "Transmission and Distribution of Electrical Energy." Attendance 94.

Los Angeles.—October 1, 1921, U. S. S. *Tennessee*, Los Angeles Harbor. The members of the A. I. E. E. Section and the Los Angeles Sections of the other technical societies were invited to visit and inspect the U. S. S. *Tennessee*, an electrically driven battleship, in the Los Angeles Harbor. Guests were divided into parties of ten or twelve, each party being in charge of one of the ship's officers. Attendance 250.

Minnesota.—October 3, 1921, Elks Club, Minneapolis. Joint meeting with local Section of A. S. M. E. Subject: "The Valuation of Public Utilities." Speaker: Mr. Delos F. Wilcox. Attendance 64.

New York.—On the evening of Wednesday, October 19, 1921 the New York Section of the Institute held a joint session with the Metropolitan Sections of the A. S. C. E., the A. I. M. E., and the A. S. M. E. The idea of holding joint sessions is a continuation of the policy adopted last year, which proved so successful, and if the attendance at this first meeting, over 1275, is a criterion, this year's meetings will prove even more successful. The subject for the evening, "Financing of Large Engineering Projects" by Arthur B. Leach of A. B. Leach & Co., Bankers, New York, proved particularly interesting. Mr. Leach devoted himself to drawing a picture of conditions as they existed in 1914 previous to the war, when the public confidence in the soundness of investments in large engineering undertakings had been established and brought that picture through all its phases, down to the present conditions. He stated that in order to regain public confidence it will be necessary to make our existing work efficient before undertaking new projects.

Immediately following this subject, Mr. Philip Cabot of White, Weld & Co., Boston, spoke on "The Engineer, A Failure as a Financial Manager" claiming that in a majority of cases the engineer both through education and natural attainments was unfitted to act as a manager, lacking chiefly an ability to visualize the future of proposed projects.

A lively discussion followed which was participated in by Calvert Townley, John H. Williams, Lewis H. Nash, A. Karminsky, B. Stevens, after which Chairman Farley Osgood reviewed the various presentations in a general way.

Pittsburgh.—October 11, 1921, Chamber of Commerce Auditorium. Subject: "Automatic Control of Motor-Generator Sets for Edison Direct-Current Service." Speaker: Mr. R. J. Wensley, of the Westinghouse Electric & Manufacturing Company, E. Pittsburgh. Mr. N. W. Storer, Vice-President of District No. 2, also addressed the meeting on the subject of more enthusiasm and greater cooperation in making the local Sections a success. Attendance 106.

Portland.—September 13, 1921, University Club. Joint meeting of the Portland Sections of the A. I. E. E. and N. E. L. A. Subject: "Regulations Under the Oregon and Washington Utilities Acts." Speaker: Mr. J. A. Laing, Vice-President of the Pacific Power & Light Company. Attendance 60.

Providence.—October 7, 1921, Providence Engineering Society. Subject: "European Practise in Electrical Switchgear and Transmission." Speaker: Mr. C. M. Moss, of the Westinghouse Electric & Manufacturing Company. The talk was illustrated by slides. Attendance 15.

Schenectady.—October 7, 1921, Edison Club Hall. Subject: "Super-Engineering." Speaker: Mr. William McClellan, President of the A. I. E. E. Attendance 200.

Seattle.—September 20, 1921, Blanc's Cafe. Annual dinner and get-together meeting. Reports were made by Chairmen of Meetings and Papers Committee and Membership Committee. During the evening a demonstration of "Wired Wireless Telephony" was given by Mr. Kalin. The Entertainment Committee arranged to have many humorous phone calls received by Messrs. Scott and Terrell. These were attached to loud speaking telephones, where they could be enjoyed by all. Prominent local engineers were called upon for an address. Chairman Growdon reported on his trip to the Salt Lake City Convention. Mr. J. B. Cox, Engineer with the General Electric Company, spoke at length on Railway Electrification on the Pacific Northwest. Attendance 57.

Spokane.—September 23, 1921, Davenport Hotel. Report of the Annual Convention by Mr. H. V. Carpenter, Section's delegate. Attendance 11.

Toronto.—September 30, 1921, C & M Building, Toronto University. Subject: "Transmission Systems." Speaker: Mr. H. C. Don Carlos, of the Hydroelectric Power Commission of Ontario. Attendance 109.

Urbana.—October 7, 1921. Subject: "European High Power Radio Stations." Speaker: Professor J. T. Tykociner. Attendance 137.

Utah.—September 21, 1921, Commercial Club. Joint meeting with the Utah Society of Engineers. Paper: "Electrolytic Production of Zinc." Author: Mr. J. T. Ellsworth, Superintendent of Zinc Plants, Judge Smelting, Mining & Refining Company. The paper outlined the general principles involved and the methods used in extracting zinc from the Park City ores. The various problems involved in the electrolytic deposition of zinc, including the tendency for other metals to deposit with the zinc, were discussed. The future of the zinc industry and some of the problems yet to be solved in electrolytic reduction were discussed. Attendance 80.

Vancouver.—September 9, 1921, Board of Trade Building. Mr. C. N. Beebe, Section delegate to the Salt Lake City Convention, gave an address outlining some of the Sections Committee discussions, and some of the papers submitted. Mr. Beebe was followed by Mr. F. W. MacNeill, who was also at the Convention, and a discussion was entered into by almost all present. Attendance 11.

Worcester.—September 29, 1921, E. E. Building, W. P. I. Paper: "Radio Telephony." Speaker: Mr. W. R. G. Baker, General Electric Company. Illustrated with stereopticon slides. Attendance 115.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—September 22, 1921. Talk by Professors McIlvaine and Hill on the advantages of the A. I. E. E. Attendance 88.

Armour Institute of Technology.—September 29, 1921. Subjects: "Activities of the American Institute of Electrical Engineers" by R. P. Burns; "Advantages Derived by Members of the A. I. E. E." by Professor Snow. Attendance 58.

Bucknell University.—September 28, 1921. Election of officers as follows: Chairman, Freeman T. Tingley; Vice-Chairman, E. LaRue Worthington; Secretary-Treasurer, John A. Ammerman. Attendance 15.

October 10, 1921. Subjects: "History of the Growth of the Electrical Engineering Course in Bucknell University" by Professor W. C. Rhodes; "Advantages of the American Institute of Electrical Engineers" by Professor Irland; "Advantages of the Bucknell Branch of the A. I. E. E. to the Electrical Students" by President Tingley. Attendance 42.

University of California.—September 14, 1921. Subject: "Railway Electrification Progress." Speaker: Mr. E. A. Palmer, Westinghouse Electric & Manufacturing Company, San Francisco. Attendance 47.

September 28, 1921. Subject: "Transformers." Speaker Mr. Walter C. Smith, of the General Electric Company. Attendance 40.

Carnegie Institute of Technology.—October 4, 1921. Election of officers as follows: Chairman, Edward A. Brand; Vice-Chairman, William S. Andrews; Secretary, Harold W. Bryan; Treasurer, Allan T. Johnston. Attendance 50.

University of Colorado.—October 6, 1921. Dean Evans spoke on the history, organization and purpose of the American Institute of Electrical Engineers; Professor Du Vall outlined some of the past activities of this Student Branch of the Institute; Professor Coover gave suggestions for the future programs for the Branch. Attendance 38.

Iowa State College.—October 5, 1921. Subject: "The Development of the Caribou Plant of the Great Western Power Company" (located on the Feather River in the Sierra Nevada Mountains). Speaker: Mr. Albert A. Northrop, of the Stone & Webster Co., Boston. The lecture was illustrated by slides and motion pictures. Attendance 135.

University of Kansas.—October 5, 1921. Talks: "Explanation of the A. I. E. E.," by Professor Shaad; introductory talks by Professors Johnson, Newman and Warner. Attendance 77.

University of Michigan.—October 12, 1921. Professor John C. Parker gave a talk in which he stated that the engineer of today is being too much advised to emphasize the social side of the profession and not enough stress is laid upon the fundamentals underlying it. Attendance 55.

University of Notre Dame.—October 10, 1921. Election of officers as follows: Chairman, John D. Fitzgerald; Vice-Chairman, Edward P. Kreimer; Secretary, Walter L. Shilts; Treasurer, Vincent J. Brown. Attendance 37.

Oregon Agricultural College.—September 28. 1921. A film loaned by the General Electric Company was shown, showing the manufacture of Electric Light Sockets. Attendance 45.

Purdue University.—September 20, 1921. Subjects: "Advantages of Belonging to the A. I. E. E." by Professor C. F. Harding; "Different Kinds of Memberships" by Professor D. D. Ewing; short talks by Professor D. L. Curtner and Mr. E. Pugh. Attendance 181.

September 27, 1921. Subject: "The Caribou Hydroelectric Plant of California." Speaker: Mr. Albert A. Northrop, of Stone & Webster Co. Mr. Northrop exhibited a number of lantern slides and four reels of moving pictures, in connection with his address. Attendance 208.

University of Washington.—October 4, 1921. Election of officers as follows: Chairman. Mr. C. Edward Allen; Secretary, Mr. Chas. A. Brokaw. Dr. Magnusson addressed the meeting with a few words of welcome and pointed out to the new student the advantages gained by affiliation with the local branch. He then introduced Mr. Geo. S. Smith, who told of some of his experiences in the engineering field since his graduation in 1916. Attendance 38.

West Virginia University.—September 28, 1921. Election of officers as follows: Chairman, H. Chandler; Vice-Chairman, C. M. Hill; Secretary, W. D. Stump; Treasurer, J. L. Hark. Attendance 25.

Yale University.—October 12, 1921. Social meeting of all members of the Electrical Engineering Department. Professor C. F. Schreiber spoke on the subject of "Evaluating Your Experiences." Short talks were also given by Professors Scott, Turner, Knowlton, Wittig and Warner. Refreshments were served. Attendance 24.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL **should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* **not** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case **and forwarded to EMPLOYMENT SERVICE, as above.**

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

The United States Civil Service Commission announces an open competitive examination for associate electrical engineer. Vacancies in the Bureau of Mines, Department of the Interior, for duty at Pittsburgh, Pa., at $3000 to $4000 a year, and in positions requiring similar qualifications throughout the United States, at these or higher or lower salaries, will be filled from this examination, unless it is found in the interest of the service to fill any vancancy by reinstatement, transfer or promotion. Applicants should at once apply for Form 2118, stating the title of the examination desired, to the Civil Service Commission, Washington, D. C., the Secretary of the United States Civil Service Board, Customhouse, Boston, Mass., New York, N. Y., New Orleans, La., Honolulu, Hawaii; Post Office, Philadelphia, Pa., Atlanta, Ga., Cincinnati, Ohio, Chicago, Ill., St. Paul, Minn., Seattle, Wash., San Francisco, Calif., Denver, Colo., Old Customhouse, St. Louis, Mo.; Administration Building, Balboa Heights, Canal Zone; or to the Chairman of the Porto Rican Civil Service Commission, San Juan, P. R.

Applications should be properly executed, excluding the medical certificate, and must be filed with the Civil Service Commission, Washington, D. C., with the material required, prior to the hour of closing business on November 15, 1921.

YOUNG ENGINEERS not over 35 years o age for training to handle electrical and me

hanical problems of erection and electrical testing in connection with telephone development in New York City. Location New York City. X-1087.

SALESMAN for a-c. and d-c. motors up to 30 h. p., and high grade electrical machinery. Location, New York City. X-1135.

ELECTICAL and MECHANICAL Constructing Engineering Company, with an established reputation for reliability acquired through many years of successful business experience, desires man to help in estimating and following up the progress of jobs. Preference will be given to a technical graduate who has had successful experience in the electrical contracting business. He must be able to give good references from former employers. Position should be permanent and lead to rapid advancement for man who can make good. X-1155.

ENGINEERS well qualified to take full charge of an office and warehouse, carrying well assorted stock of high-grade steel products, embracing high-speed steels, complete line of tool steels, drill steels, spring steels, machinery steels, etc. Must be thoroughly trustworthy and well recommended. Must be experienced steel salesman, as well as practical men, thoroughly familiar with modern methods of heat treating and qualified to act as demonstrators. In other words, they should be conversant with the quality steel business and should be ideal salesmen in every sense of the word. Would also be desirable if those men understood conditions peculiar to Eastern markets. Application by letter outlining in detail experiences and references, together with idea of salary or drawing account, rate of commission, length of contract, etc. Location, Far East, China, and Japan. X-1166.

SALES ENGINEER for a concern supplying steam for the operation of dynamo engines, pumps, refrigerating equipment, heating apparatus, etc. Practical experience in connection with the operation of dynamo engines, and pumps in isolated plants such as office buildings, hotels, etc. Must have had experience in selling. Location, New York City. X-1168.

SALESMAN to sell electrical safety switches. To take charge of a district office and supervise the work of two other salesmen. Should have technical education or thorough knowledge of the use of electricity, and where and why switches are required. It is our intention to develop a model district office, utilizing the principle of scientific management which has proved very successful in handling our production during the last five years. Under this plan we would have an Engineering and a planning department and district sales manager would have his work scheduled as well as that of the salsemen working for him. Location, Michigan. X-1176.

DRAFTSMAN with engineering degree, must be thorough in physics and well experienced in chemistry and light, also to have knowledge of electricity for the purpose of designing mechanical and electrical details. Man having experience of waters and gases preferred. Must be highly recommended for confidence. No other than those who can well qualify need apply. Location, New Jersey. X-1211.

INSTRUCTOR preferably with previous teaching experience in theoretical mechanics and mechanics of materials, for state university. Location, South. X-1214.

EQUIPMENT ENGINEER. Facilities layout, etc., of telephone central office equipment with large operating company. Give details of past experience, age and present and expected salary, etc. Location Ill. X-1220.

SALES ENGINEERS by company selling heat insulating materials on national scale. Present openings New York and Chicago. Splendid opportunity for progressive men with some previous selling experience. X-1215.

GRADUATE ELECTRICAL ENGINEER with two or three years experience for research work on electric meters. X-1233.

ENERGETIC ELECTRICAL man with executive, estimating and new business abilities, to take complete management of a going electrical contracting and repair business. May invest if desired. Location Brooklyn, N. Y. Application by letter. X-1241.

PHYSICIST experienced in physical chemistry and thermochemistry. At least three years research experience. Location New Jersey. X-862.

MEN AVAILABLE

TECHNICAL GRADUATE in electrical engineering, thoroughly grounded in chemistry, desires position with opportunity for advancement in Southeastern Ohio, but would gladly consider other locations. Unmarried and can furnish good references. E-3012.

MECHANICAL-ELECTRICAL ENGINEER Technical graduate, G. E. Test. Age 37, fourteen years practical experience in the design, construction and operation of steam, hydroelectric and factory plants in responsible charge as, chief engineer, engineer of works and general superintendent. Desires position with room for advancement. E-3013.

ELECTRICAL ENGINEER—B. S. Degree, age 23, single. One year's experience as foreman electrician in manufacturing plant. Desires position in electrical and mechanical maintenance. E-3014.

HEATING DEVICE ENGINEER—Electrical engineer, age 27, married, experienced in electrical heating devices, is looking for opening in Chicago. Small company preferred. Have had experience with large manufacturer of above appliances. Available upon two weeks' notice. E-3015.

ELECTRICAL ENGINEERING GRADUATE of a four-year recognized technical school desires a position with an electrical concern. 1921 graduate, age 24, single. Position in power plant or substation of power company or electrical railway accepted if there is a chance for advancement. Reference supplied if desired. Employed at present but available on short notice. Location immaterial. E-3016.

TECHNICAL GRADUATE of Electrical Engineering course, '20, age 26, unmarried, four years experience in sales work. Desires position as salesman with a well established company. Prefer to sell electrical supplies. Will go anywhere. Initial salary immaterial. Available on short notice. E-3017.

ELECTRICAL ENGINEER, age 20, college graduate, ten weeks experience, General Electric Company's testing department. Desires position with engineering, manufacturing, or light and power company, where opportunity for advancement is presented. Location, New York City or vicinity preferred, but am willing to go West if necessary. Available immediately. E-3018.

ELECTRICAL ENGINEER—12 years in research and development work on motor control for general motor applications, including traction, electric automobiles and trucks. Age 33; married; graduate in electrical engineering. Member A. I. E. E. and S. A. E. E-3019.

MANAGER OR SUPERINTENDENT, electrical and mechanical engineer, executive ability, age 38, married, thoroughly trained, wishes change and opportunity for advancement. First class experience in manufacturing, installation of electrical apparatus, electric railway track and equipment construction and maintenance, and general management of railways. Good at dealing with labor and public relations. At present located in Canada. E-3020.

ELECTRICAL ENGINEER, available for domestic or foreign service. Graduate student course Westinghouse Company. Experienced in design of central stations and transmission lines. Member A. I. E. E. Age 31, married. Additional information upon request. E-3021.

ELECTRICAL ENGINEER, university graduate, age 27 years. Three years experience at the plants of the General Electric Company and two years experience in the construction and layout of power houses and substations for rubber plants, glass works steel mills and coal mines. E-3022.

ELECTRICAL GRADUATE—Assoc. A. I. E. E. Competent, age 30. Five years maintenance foreman; d-c. and a-c. apparatus; four years laboratory tests; one year New York Edison tests. Desires position in vicinity of New York, offering an opportunity for advancement. Good references furnished. Available at once. E-3023.

FIRST CLASS ELECTRICIAN—Age 31, married. Maintenance motor and generator work and factory installation, 13 years experience. Available immediately. Northern New York preferred. Associate A. I. E. E. E-3024.

ELECTRICAL DISTRIBUTION ENGINEER, technical graduate, age 28, married. Experience includes G. E. test course, construction and operation of generating stations, construction and design of overhead lines. Desires place as assistant to electrical engineer or assistant to manager of progressive central station company. Responsibility wanted. E-3025.

POWER AND MECHANICAL ENGINEER, technical graduate, B. S. and M. E., age 30, eight years experience along broad lines, machine shop, metallurgy, chemical manufacturing, sugar engineering, industrial and power plant practise, operation, design, layout, calculations, heating, distribution of steam, water, etc. Has business and executive ability. Desires responsible position. E-3026.

ELECTRICAL ENGINEER, technical graduate, age 26. Three years experience in electrical drafting and layout. Experience in sales engineering. Wishes position as electrical or sales engineer. Would consider establishing agency. Single. Location preferred New York City. E-3027.

GRADUATE ELECTRICAL ENGINEER, Case 1920, age 23. Westinghouse graduate student course, eight months engineering experience on industrial motors at Westinghouse. At present on substation construction. Desires position in engineering or construction department of progressive power company. Middle west or eastern location preferred. Available on short notice. E-3028.

MOTORS AND MOTOR-DRIVEN MACHINERY are my specialty. Five years with large motor manufacturer and four years with well-know manufacturer of electrically driven machinery as head of department. Practical engineer with unusual theoretical knowledge, B. S. and E. E. degrees. University of Illinois. Some teaching experience. Consulting or designing accepted. E-3029.

GOOD, LIVE, WIDE AWAKE ELECTRICAL ENGINEER—Technical graduate, desires position requiring initiative, tact, and engineering ability. Four years General Electric Laboratory—Tests—Radio and Sales. Location preferred Middlewest. Available on short notice. E-3030.

ELECTRICAL ENGINEER—Age 36, married Ten years overhead and underground construction. Three years sales engineer, high-tension distribution specialties. Three years manager engineering sales electrical supply house. Circumstances render it necessary to make Chicago permanent residence. Desire to represent electrical manufacturer on salary and commission basis. Exceptional references. E-3031.

ELECTRICAL ENGINEER—Age 34, single, technical graduate, two years General Electric Company. Testing Department, two years public utility company, five years research work on automotive equipment; desires position as experimental or research engineer. Associate A. I. E. E. and American Mathematical Society. E-3032.

TECHNICAL STUDENT—Age 23, desires position with electrical duties, in laboratory or office of electrical engineering concern; 5th year student in E. E. at Cooper Union Night. Four years clerical, three years practical experience. E-3033.

GRADUATE MECHANICAL AND ELECTRICAL ENGINEER, export and import

manager, age 38, member American Chamber of Commerce, Paris-London, six years in far East, seven languages, open for new connection. E-3034.

ENGINEER-EXECUTIVE of eighteen years experience manufacturing, designing, sales engineering on motors, controllers, batteries, cranes and hoists; seven years college training; broad, resourceful, energetic, agreeable. Salary $5700. Five years present responsible position; ten years with another well-known engineering force. Seeks position factory manager, chief engineer or sales engineer. E-3035.

ELECTRICAL ENGINEER—Age 35, technical graduate, fourteen years experience in industrial and public service power plants in construction, maintenance and operation, desires position as manager of electric plant, or electrical engineer for industrial plant. Available on short notice. Western states preferred. Assoc. A. I. E. E. E-3036.

ELECTRICAL ENGINEER—Technical graduate, age 34, married; Assoc. A. I. E. E., ten years experience in construction, maintenance, and testing; desires position with future; can handle men and deal with public successfully. Location U. S. Available immediately. E-3037.

ELECTRICAL-MECHANICAL ENGINEER—Technical graduate, broad practical engineering experience. Ten years experience in power plant, substation and electrical construction work. This includes estimating, design, specifications, purchasing and supervision of drafting and erection work. Well versed in problems in connection with power plant economics and electric railways. Available on short notice. E-3038.

ELECTRICAL ENGINEER—Technical graduate, ten years experience, testing, operating, designing, construction and managing electrical utilities. Can furnish good references. Am a strong executive and good organizer. Present salary $3000. Age 31. Married. Mem. A. I. E. E. E-3039.

ELECTRICAL - MECHANICAL INDUSTRIAL AND DESIGNING ENGINEER—Age 42; university graduate; able executive. Fifteen years' shop, office and field experience, in estimating, appraisal, engineering economics, design, construction and equipment of power plants, substations and factories. Salary in proportion to responsibilities. E-3040.

ELECTRICAL ENGINEER—Technical graduate, Associate A. I. E. E., with nine years experience in design, construction and operation of central stations, and power applications to railways and mining properties, desires to make connection with construction or operating company or consulting engineer engaged in above lines. E-3041.

ELECTRICAL ENGINEER, experienced in central station industry, experimental engineering laboratory, and teacher of electrical engineering. Desires to connect with concern requiring the services of a capable, energetic, and conscientious man. Salary requirements moderate. Age twenty-eight years. Married. E-3042.

HYDROELECTRIC SUPERINTENDENT—Age 31, married, fourteen years excellent practical experience on construction operation and maintenance of power systems, seven years in foreign service of United States Government, can handle men and produce results. At present holding responsible position with large power company on Pacific Coast. Desires to locate permanently in New York State. Associate A. I. E. E. E-3043.

SALES ENGINEER—Age 35, married. Ten years exceptional sales record calling on electrical jobbing, contractor and industrial trade in central West, South and parts of East. Six years present connection manufacturing plant. Familiar with modern factory methods and production, machine design, foundry practise and die and pattern design. Also six years design manufacturing and operation of telephone equipment. Available 30 days. Present location Ohio. E-3044.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER-Married, age 29, desire position where my experience will fit in, four years with Westinghouse Electric & Manufacturing Company, assembling, testing, designing and engineering. Two years with steel company, construction, power house operating, trouble and operating both in the mill and office switchboard designer and sales engineer. E-3045.

EXECUTIVE—Publicity and advertising, sales promotion, technical journalist, progressive, successful writing experience covering newspaper, magazine and industrial fields. Formerly special writer on leading New York business daily on business news. Have been assistant advertising manager of the Edison Storage Battery Company, and for more than two years assistant editor of Science & Invention. Desire connection where initiative and executive ability assure position limited only by my own capabilities. Salary to start $2500 year. New York or vicinity. E-3046.

TECHNICAL GRADUATE—B. S. 1920. Student A. I. E. E., age 24, unmarried, desires position as fire inspector with some insurance inspection bureau. Fifteen months experience rating under the Dean Schedule. Good references, now employed; available about January 1st. E-3047.

INDUSTRIAL ENGINEER—Now electrical engineer of works with 4000 lamps, 1200 motors, 120 traveling cranes, 10 locomotive cranes, power plant with alternating and continuous-current equipments, etc. Mem. Am. Soc. M. E., A. I. E. E., A. E. S., I. E. S., I. & S. E. E., A. A. A. S., etc. Age 34; salary desired $6000. E-3048.

ELECTRICAL ENGINEER, age 30. Single, A. I. E. E., A. S. M. E. and A. I. & S. E. E. Six years mining and steel mills electrical work, one year estimating and designing, one year purchasing electrical equipment. Two years foreign electrical construction. Available two weeks; location anywhere. E-3049.

ELECTRICAL ENGINEER—Assoc. A. I. E. E., age 38, married. Fifteen years electrical engineering experience. Last five years engineer in charge high-tension distribution, power plant design and construction. Heavy electric traction. Desires connection with some engineering concern in same capacity or as consulting engineer with some municipality. Salary $3000. E-3050.

SUPERINTENDENT—Mechanical and electrical, power plant construction preferred. Can qualify as plant or maintenance engineer for manufacturing or chemical concerns. Fifteen years experience, four years hydroelectric construction, maintenance and operation. University graduate, age 35. Present salary $350. Would consider taking up sales work at some sacrifice in salary to start. E-3051.

ELECTRICAL ENGINEER—B. S. E. E. degree; Assoc. A. I. E. E., married, age 35. Ten years varied experience; three years appraisal of electrical properties; one year motor repair; three years construction, inspection, shop and test; three years construction, installation, maintenance and operation as chief electrician. Desires position of taking charge of electrical department of large industrial plant or acting as assistant to consulting electrical engineer. Salary $3000. Location, Pacific slope or north-west. Available February 1, 1922. E-3052.

ENGINEER—Jr. A. S. M. E., Assoc. A. I. E. E., desires position construction work, maintenance or operation. Experience with a-c. and d-c. twelve years practical. At present superintendent construction department of large electric company. E-3053.

ELECTRICAL ENGINEER—Graduate 1921, age 26, single, desires position with hydroelectric or power transmission construction company doing work in foreign country. South America or Mexico preferred. Available at once. E-3054.

ELECTRICAL ENGINEER—Age 34, married, university education, desires position with company offering opportunity for advancement. Ten years experience in charge of central station operation, including high-tension substation, conduit construction and cable installation, overhead distribution and plant operation. Can furnish references. Salary $4000. Available on reasonable notice. E-3055.

ELECTRICAL ENGINEER—Age 27, married, technical education, seeks connection with manufacturing concern as head of electrical department. Six years experience installation, operation and maintenance of power and electrical equipment, including one year experimental and development work in electrical laboratory. Associate A. I. E. E. Executive ability. Location immaterial. Available immediately. E-3056.

EXECUTIVE OR CONSULTING ENGINEER—Very broad experience in electrical field including practically all phases of industrial electrical engineering such as power plant design, motor layouts, lighting installations, transmission and distribution system, specifications, estimates, appraisals, reports, etc. Six years experience in electrical manufacturing companies, twelve years in responsible charge of the industrial electrical engineering work of one of the largest engineering firms of the country. Open for engagement January 1st as executive or consulting engineer. E-3057.

ELECTRICAL ENGINEERING GRADUATE, Assoc. A. I. E. E. Experience includes general wiring, telephone exchange installation and maintenance, four years in motion picture projection field. Desires position with concern in Cleveland or vicinity. Initial salary secondary. Work must be attractive and offer advancement and future in recognition of hard work. Age 24. Present salary $2600. E-3058.

EXECUTIVE — CONSTRUCTION ENGINEER (ELECTRICAL)—Age 30. Will take entire charge of construction. Thoroughly familiar with design, selection, operation and installation of radio equipment for marine and coastal stations. Experienced layout and construction complete stations, including erection masts, antenna and buildings. Also installation switchboards, transmitters and auxiliaries. Interviews New York and vicinity. E-3059.

ELECTRICAL ENGINEER—B. S. degree 1919, age 23, single, desires position in the East. Energetic and hard worker, with two years steel mill experience on construction and maintenance. Also design work on a-c. and d-c. magnetic control. Available on moderate notice. E-3060.

RADIO ENGINEER, technical graduate; age 34, with twelve years experience in design construction and operation of high power radio stations and the installation of various types of receiving apparatus, is open for position with radio concern or with firm where experience with high power high frequency may be useful. E-3061.

UTILITY MANAGER AND ENGINEER. Broad experience in construction and operation of all classes of utilities, including refreigeration, desires similar position or connection with a manufacturing company to work into sales department. Successful in the sale of securities and power. E-3062.

ELECTRICAL ENGINEER, technical graduate; age 30; married. Desires position with large industrial plant or big mining company. Three years with Westinghouse Co. in their main shop and service department. Last six years engineer in full charge of installation and repair in iron mines in New Jersey. Location, Atlantic Seaboard. E-3063.

GRADUATE ELECTRICAL ENGINEER, single; age 25. Desires situation with central station, consulting engineer or manufacturing company. Four years experience. Electrical testing, factory accounting, army officer, public utility, appraisal and construction. Opportunity not immediate salary main consideration. Available at once. E-3064.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED OCTOBER 14, 1921

AINSWORTH, STUART, Assistant Engineer, Peruvian Corporation, Ferrocarril del Sur., Arequipa, Peru, S. A.

ALONZO, FRANCISCO F., Electrical Tester, Westinghouse Elec. & Mfg. Co.; res., 114 S. Negley Ave., Pittsburgh, Pa.

ALSOBROOK, HENRY L., Asst. Repeater Chief, Western Union Telegraph Co.; res., 2108 Green St., Columbia, S. C.

ASHMORE, JOSEPH, Electrical Engineer Surveyor, British Engine Boiler & Electrical Insurance Co., Ltd.; res., 28 Fulford St., Old Trafford, Manchester, England.

AUBERT, FRANCIS, Asst. Electrical Engineer, Distribution Dept., Mexican Light & Power Co., 7a de Durango 118, Mexico City, Mex.

BARON, ROBERTO J. B., 13 Rua Paulino Affonso, Petropolis, Est. D. Rio, Brazil, S. A.

BATES, EARL J., Electrical Engineer, Research Dept., National Cash Register Co.; res., 515 Albany St., Dayton, Ohio.

*BAYLE, RUSSELL M., Service Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1219 Mill St., Wilkinsburg, Pa.

BELL, TRICE MORTON, Engineer, General Electric Company; res., 417 Union St., Schenectady, N. Y.

BOND, THOMAS KIRK, Civil Engineer, Utah Consolidated Mining Company, Tooele City, Utah.

BOOTH, JOHN A., Transformer Engineer, British Thomson-Houston Co., Ltd., Rugby, England.

BUGEJA, CHARLES, Tester, Electrical Construction Dept., Brooklyn Edison Co., 569 Fulton St., Brooklyn, N. Y.

BUSH, CLARENCE R., Electrical Construction Engineer, Central Illinois Light Co.; res., 1033 North St., Peoria, Ill.

BUTLER, V. DELL, Foreman, Power Plant, Portland Railway, Light & Power Company, Bull Run, Oregon.

CASTRO, JORGE E., Superintendent, Testing Meters, Mexican Light & Power Co., Gante St. No. 20, Mexico City, Mex.

COFFIN, CHARLES D., Draftsman, New England Tel. & Tel. Co., Lowell; res., Tyngsboro, Mass.

COLABAWALA, JEHANGIR R., Executive Engineer, The Parbati Hydro-Electric Irrigation & Water Works Project, Morar, C. India.

COX, ASA WALTER, Electric Foreman, Carnegie Steel Company, McDonald; res., 2712 Alma Ave., Youngstown, Ohio.

CRAIG, ALBERT G., Assistant Engineer, United Electric Light & Power Co., 130 E. 15th St.; res., Apt. D1, 2440 Webb Ave., New York, N. Y.

CUNNINGHAM, JOHN T., Student, Heffley Institute; res., 136 Nostrand Ave., Brooklyn, N. Y.

DAVISON, GEORGE E., Asst. Engineer, Virginia Railway and Power Co.; res., 215 So. Mulberry St., Richmond, Va.

DE LOACHE, ROBERT LEE, Switchboard Designer, Westinghouse Elec. & Mfg. Co., 56 Magnolia St., Atlanta, Ga.

EGEE, JOSEPH W., Sales Engineer, Electric Appliance Company, New Orleans, La.; res., 21 Adams St., Montgomery, Ala.

ELIESON, EDWIN E., Electrician, American Smelting & Refining Co., 327 Vine St., Murray, Utah.

FRANKEL, CHARLES B., Assistant Engineer, Underground Extensions, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*FREUCHEN, THORD H., Electrical Designer, Braden Copper Co., Rancagua, Chile, S. A.

FRIEND, HENRY M., Asst. Electrical Inspector, Engineering Material, U. S. Navy, 44 Court St., Brooklyn; res., 316 W. 97th St., New York, N. Y.

FUKAMI, GEN-ICHIRO, Electrical Engineer, Mitsubishi Shipbuilding Co., 120 Broadway, New York, N. Y.

GARDNER, MURRAY F., Testing Laboratory, American Steel & Wire Co., Worcester, Mass.; res., 508 N. Capitol Ave., Lansing, Mich.

GIBBON, THOMAS HUTCHINSON, Electrical Engineer, Engineering Dept., Canadian General Electric Co.; res., 49 Gilmour Ave. Toronto, Ont.

GILDER, THOMAS N., Asst. Engineer, Valuation Dept., Portland Railway, Light & Power Co., Electric Bldg., Portland, Ore.

GILL, CLARENCE RHODES, Electrician & Student, Dynamo Laboratory, University of Wisconsin, Madison, Wis; res., 5708 Harper Ave., Chicago, Ill.

GONZALEZ, ARTURO, JR., Superintendent, District No. 2, Porto Rico Railway, Light & Power Co., San Juan, P. R.

GOODWIN, RALPH J., Superintendent & Electrical Engineer, Municipal Electric Plant, Dothan, Ala.

GRUNER, RAYMOND W., Sales Dept., Allis-Chalmers Mfg. Co., Milwaukee; res., 5031 National Ave., West Allis, Wis.

GUIDONI, ALESSANDRO, Lieut-Col., Air Attache, Italian Embassy, 1400 New Hampshire Ave., Washington, D. C.

HALDEMAN, THEODORE T., Superintendent of Public Works, Borough of Chatham, Chatham, N. J.

HALL, JACK H., E. E., Lihue Plantation Co., Ltd., Lihue, Kauai, T. H.

*HALPERIN, HERMAN, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

HARROP, EVERETT T., Field Engineer, New England Telephone & Telegraph Co.; res., 30 Crystal St., Worcester, Mass.

HATCH, PHILIP H., Student Engineer, General Electric Company, Schenectady; res., 425 Pelham Manor Road, Pelham Manor, N. Y.

HAUSER, ALBERTO, Superintendent of Connections & Electrical Control Depts., Mexican Light & Power Co., Mexico City, Mex.

HEIMBACH, ELBERT B., Electrical Engineer, American Appraisal Co.; res., 502 35th St., Milwaukee, Wis.

HICKOCK, HAROLD CLARK, Engineer, General Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

HUANG, YOUNG-TSIEH, Student-Engineer, Bell Telephone Company of Pa., Philadelphia, Pa.

INOUE, FUKUTANE, Chief Engineer, Hanshin Express Electric Railway Co., Osaka, Japan; Mitsui & Co., 65 Broadway, New York, N. Y.

JEFFERSON, WILLIAM E., Engineering Dept., Maritime Tel. & Tel. Co., Ltd., Halifax, N. S.

JOHNSON, CARL W. D., Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

*KEEFE, WALTER L., Electrician, Lord Electric Co., 112 Water St.; res., 8 Irving St., Boston, Mass.

KOMATSU, MOHACHI, Engineer, Patent Dept., Tokyo Electric Co., Kawasaki, Japan.

KROGH, GUNNAR E., Engineering Office, Elektrodrift, Sjofartsbygingen 450, Kristiania, Norway.

KUROYANAGI, KENKICHI, Electrical Engineer, Oi Works, I. G. R., Oimachi, Tokyo, Japan.

LANE, DAVID M., Assistant Engineer, William Barclay Parsons, 84 Pine St., New York, N. Y.; res., 584 Jersey Ave., Jersey City, N. J.

LAVARELLO M, JUAN J., Electrical Sub-Foreman, Coya Power House, Braden Copper Co., Rancagua, Chile, S. A.

LEADER, ALVA A., Electrical Contractor, Kingman, Ariz.

LEIGHTON, HAROLD W., Radio Electrician, & Laboratorian, Navy Yard, Boston; res., 3 Quincy St., Somerville, Mass.

*LEROUX, HERMANUS S., Bethulie, O. F. S, So. Africa.

MACIAS, CARLOS, Manager & Engineer of Electromotor, S. A., Isabel La Catolica 43, Mexico, D. F.

MACKAY, ST. CLAIR, Paymaster, L. K. Comstock & Co., Inc., 21 E. 40th St., New York, N. Y.

MARSHALL, JOSEPH H., 509 East 77th St., New York, N. Y.

MATFL, EMIL, Electrical Operator, Edison Electric Illuminating Company, Boston, Mass.

*MATTHEWS, THOMAS, Instructor, University of North Dakota, Grand Forks, N. Dakota.

McINNES, EDWARD H., Resident Engineer, Western Electric Company, Wellington, N. Z.

McLAUGHLIN, GEORGE S., Transitman & Inspector, City Engineer's Office; res., 145 S. Garfield Ave., Pocatello, Idaho.

MERCER, GEORGE G., School of Electrical Engineering, Purdue University, La Fayette, Ind.

METLIE, PAUL J., Testing Dept., Allis-Chalmers Co.; res., 5031 National Ave., West Allis, Wis.

MITCHELL, CHARLES T., Municipal Electrician, Municipal Hall, Kerrisdale; res., 2033 Trafalgar Road, Vancouver, B. C.

MORISHIMA, TEIICHI, Vice-Chief of Design Dept., Hitachi Engineering Works, Sukegawa Ibarakiken, Japan.

MULLER, KARL E., Dr., Electrical Engineer, Mexican Light & Power Co.; res., 4a, Durango 59, Mexico, D. F., Mex.

NARAYANAN, MANAKAL S. I. A., Assistant Engineer, Public Works Dept., Pyinmana, Burma, India.

PAOLINO, SERAFINO, Elec. Draftsman, Pacific Gas & Electric Co., San Francisco; res., Tiburon, Marin County, Calif.

PEEPLES, RICHARD G., Electrical & Mechanical Engineer, 136 N. Central Ave., Phoenix, Ariz.

PETERSEN, JOHN D., Electrical Engineer, Maxwell Motor Co., Inc., Oakland Ave., Detroit, Mich.

PINELES, SETH M., Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 7111 Reynold St., Pittsburgh, Pa.

PIOCH, FRANK H., Chief Electrician, Glogora Coal Co., Montcoal, W. Va.

POTTS, HAROLD R., Switchboard Operator, New York Edison Co., 98 Vandam St., New York; res., 280 Rutledge St., Brooklyn, N. Y.

QUINLAN, JOSEPH M., Salesman (Motors & Plant Equipment), Hawaiian Electric Co., Ltd., King St., Honolulu, T. H.

RAMINEZ, JAVIER P., Draftsman, Mexican Light & Power Company, Mexico City, Mex.

REES, EDWARD H., Electrical Engineer, Illinois Glass Co., Alton, Ill.

REID, IRL C., Receiving Engineer, Radio Corporation of America, Koko Head, Oahu, T. H.

ROSS, FRANK W., Asst. Cost Engineer, Lehigh Power Securities Corp.; res., 323 N. 8th St., Allentown, Pa.

SCHANZ, JOHN, JR., Student of Electrical Engineering; res., 230 E. 18th St., New York, N. Y.

SCHEINBEIM, HYMAN, 1517 Charlotte St., New York, N. Y.
SCHOLZ, HERBERT J., Lighting Engineering Dept., General Electric Company, Schenectady, N. Y.
SMART, LEE ROY, Service Inspector, American Tel. & Tel. Co., 311 W. Washington St., Chicago, Ill.
SMITH, CHARLES H., Electrical Contractor & Engineer, 78 2nd St., San Francisco; res., Mill Valley, Calif.
SMITH, GEORGE M., Valuation Engineer, Murrie & Co., 74 Broadway, New York, N. Y.; res., 310 Hillside Ave., Newark, N. J.
SMITH, WALDORF ASTOR, Rayville, Louisiana.
SOLIS, GREGORIO, Inspector of Local Distribution, Mexican Light & Power Co., Sucursal, B-Mexico, D. F.
SOUJA, ODILON E. do A., Chief of Electrical Construction Dept., Sao Paulo Tramway, Light & Power Co.; res., Avenida Turmalina 7 (Acelimacao), S. Paulo, Brazil, S. A.
SPENCER, THOMAS G., Asst. Supt., Cable Plant Western Electric Co., Ltd., North Woolwich, London, S. E., Eng.
STECHER, LEWIS J., Lieutenant Commander, U. S. S. Wyoming; New York, N. Y. res., 16 Union Ave., Schenectady, N. Y.
SUTTON, PORTER O., President & Engineer, Norfolk Electric Mfg. Co., 217 Cumberland St., Norfolk, Va.
TAKAO, NAOSABURO, Director, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.
TAMAGAWA, HISAO, Chief Electrical Engineer, Electrical Dept., Hitachi Mine, Ibaraki-ken, Japan.
TAO, FENG-SHAN, Student Engineer, Bell Telephone Company of Pennsylvania; res., 1830 S. Logan Square, Philadelphia, Pa.
THOMPSON, LAWRENCE F., Asst. Construction Engineer, The Mountain States Tel. & Tel. Co., Salt Lake City, Utah.
TUNISON, LESTER E., Substation Operator, Southern California Edison Co., res., 1606 Ingraham St., Los Angeles, Cal.
WARD, OSCAR P., Electrician, Paintsville, Ky.
WARD, RICHARD H., Manager, Ringsdorff-Werke, A. G., 521 W. 23rd St., New York, N. Y.
WEIR, WILLIAM S., Engineer-in-Charge Power Station, Glasgow Corporation Tramways; res., 8 Scotia St., Glasgow, Scotland.
WILLIAMS, ALEC D., Electrical Engineer, The Broken Hill Proprietary Co., Ltd., Broken Hill, N. S. W., Aus.
WILLIAMS, H. L., Manager, Evanston Electric Light Co., Evanston, Wyoming.
WILLIAMS, ISABELLE CONKLING, Telephone Engineer, Western Electric Co., 463 West St., New York; res., 28 Covert Place, Flushing, N. Y.
YOKOTA, CHIAKI, Charge of Switchgear Design Dept., Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.
YOSHIDA, GENZO, Commercial Electrical Engineer, Engineering Dept., Mitsui & Co., 65 Broadway, New York, N. Y.

Total 106.

*Former enrolled students.

ASSOCIATES REELECTED OCTOBER 14, 1921

FAUCETT, FRANK FIELDING, Chief Engineer, Enterprise Electric Company, 521 1st Ave., Spokane, Wash.; Joseph, Ore.
MORGAN, THEODORE BLACKWELL, Asst. Superintendent, Southern Division, Public Service Electric Co.; res., 18N. Eastfield Ave., Trenton, N. J.
WADE, MARK LEIGHTON, 2867 Graveley St., Vancouver, B. C.

MEMBER REELECTED OCTOBER 14, 1921

FISHER, HARMON FRANCIS, Liguefaction Engineer, U. S. Bureau of Mines, 2116 Interior Bldg., Washington, D. C.

FELLOW REELECTED OCTOBER 14, 1921

PIKLER, HENRY, Managing Director, Teudloff-Dittrich Mfg. Co.; res., 30 Ulloi-ut, Budapest, Hungary.

MEMBERS ELECTED OCTOBER 14, 1921

DUNMIRE, RUSSELL P., Commerical Engineer, Westinghouse Elec. & Mfg. Co., Union Bank Bldg., Pittsburgh; res., Irwin, Pa.
GOULD, HAROLD M., Electrical Engineer, Dept. of Street Railways, Murphy Bldg., Detroit, Mich.
KILLEBREW, EMMET S., President, Albany Electric Co., 126 Court Ave., Albany, Ga.
KUBACH, WILLIAM L., Electrical Engineer, National Lamp Works of G. E. Co., Nela Park, Cleveland, Ohio.
PENN, MARION, Plant Engineer, Public Service Electric Company of New Jersey, Newark; res., 35 Elmwood Place, Elizabeth, N. J.
SMITH, LEON E., Commercial Engineer, General Electric Co., W. Lynn, Mass.
VAL DAVIES, ARTHUR E., Asst. City Electrical Engineer, Corporation of the City of Cape Town, Dock Road Power Station, Cape Town, S. Africa.

TRANSFERRED TO GRADE OF MEMBER OCTOBER 14, 1921

BRUEGGEMAN, FRANK, Asst. Mechanical & Electrical Engineer, South Park Commissioners, Chicago, Ill.
CHRISTIANSEN, KAY C., Electrical Engineer & Supt. of Elec. Construction, Phoenix Utility Co., Hazleton, Pa.
COLVIN, C. W., Asst. Appraiser & Chief Engineer, Appraisal Dept., British Columbia Electric Railway Co., Ltd., Vancouver, B. C.
CONDON, EDWARD J., President, Condon Engineering Co., Chicago, Ill.
CURTIS, ALFRED S., Telephone Engineer, Western Electric Co., New York, N. Y.
DAVIDSON, JOHN, JR., Telephone Engineer, American Telephone & Telegraph Co., New York, N. Y.
DEMAREST, CHARLES S., Electrical Engineer, American Telephone & Telegraph Co., New York, N. Y.
FAIRLEY, G. E. A., Engineer, Buildings and Grounds, Carnegie Institute of Technology, Pittsburgh, Pa.
FIELD, CROSBY, Engineering Manager, National Aniline & Chemical Co., Inc., New York, N. Y.
HALL, GERALD R., Engineer, Apparatus Sales Dept., Canadian General Electric Co., Toronto, Ont.
HAMDI, ABDULLAH F., General Foreman, Test Dept., New York Edison Co., New York, N. Y.
KITTREDGE, CARLYLE, Chief Engineer, Michigan State Telephone Co., Detroit, Mich.
LYTHGOE, JOSEPH, City Electrical Engineer, Christchurch, New Zealand.
MALTHA, GERARD S., Chief Designing & Estimating Engineer, Ebro Irrigation & Power Co., Barcelona, Spain.
MANVEL, FREDERIC I., Installation Engineer, General Electric Co., Pittsfield, Mass.
MORGAN, FRED, Electrical Engineer, Sessions Engineering Co., Chicago, Ill.
NEWLIN, EARL M., Engineer, Superpower Survey, U. S. Geological Survey, New York, N. Y.
PAGE, ROY, General Superintendent, Nebraska Power Co., Omaha, Nebr.
PARSONS, OLIN D., Telephone Engineer, Western Electric Co., New York, N. Y.
PLUMB, HYLON T., Local Engineer, General Electric Co., Salt Lake City, Utah.
PROEBSTEL, D. W., Asst. Engineer, Portland Railway, Light & Power Co., Portland, Ore.
RAKESTRAW, CLAUDE N., Supt. of Lines, Cleveland Electric Illuminating Co., Cleveland, O.
SUTHERLAND, WILLIAM F., Designing Engineer, Toronto Hydro-Electric System, Toronto, Ont.
WARWICK, JOHN F., Engineer, Georgia Railway & Power Co., Atlanta, Ga.
WELLER, CLIFFORD T., Engineer, Gen. Engineering Laboratory, General Electric Co., Schenectady, N. Y.
WORK, WILLIAM R., Prof. of Elec. Engineering Carnegie Institute of Technology, Pittsburgh Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held September 30, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

GILL, LESTER W., Professor of Electrical Engineering, University of British Columbia; Consulting Engineer; Vancouver, B. C.
GRACE, SERGIUS P., Engineer on Foreign Wire Relations, American Telephone & Telegraph Co., New York, N. Y.

To Grade of Member

CLARK, JAMES C., Associated Professor Electrical Engineering, Stanford University, Stanford University, Calif.
FITZGERALD, THOMAS W., Professor of Electrical Engineering, Head of Department Georgia School of Technology, Atlanta, Ga.
HANSON, C. F., Director of Electrical Research Habirshaw Electric Cable Co., Yonkers, N. Y.
MORGAN, THEODORE B., Asst. Supt., Southern Division, Public Service Electric Co., Trenton, N. J.
MUIRHEAD, JAMES, Government Inspector of Electrical Energy, Province of British Columbia, Vancouver, B. C.
PERTSCH, JOHN G., JR., Assistant Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.
SCHARNBERG, HERMAN J. B., General Superintendent, Palma Soriana Sugar Co., Oriente, Cuba.
WHITEHURST, ROLAND, Manager, Washington Branch, Electric Storage Battery Co., Washington, D. C.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before November 30, 1921.

Amstutz, J. Oscar, New York, N. Y.
Ard, Lignon B., New York, N. Y.
Baker, Charles L., Green Bay Wis.
Bang, Claus, Three Rivers, Que.
Barrer, Glen A., Chicago, Ill.
Barton, Rensselaer G., Seattle, Wash.
Bibber, Harold W., Cambridge, Mass.
Bisdee, Colin E., Schenectady, N. Y.
Cooper, Herbert W., Worcester, Mass.
Cronstedt, Harry G., New York, N. Y.
Crooke, Roscoe J., (Member), Seattle, Wash.
Daymude, Earl L., Seattle, Wash.
De Chesne, Herbert E., Seattle, Wash.
Delsasso, Leo P., Los Angeles, Cal.
Emery, Howard L., Worcester, Mass.
Evans, Willard M., Pittsburgh, Pa.
Evenson, Franklin F., Los Angeles, Cal.
Fleming, George A., Los Angeles, Cal.
Foreman, Walter E., Toronto, Ont.

Freeman, Newell L., St. Louis, Mo.
Fuller, Andrew B., Seattle, Wash.
Fung, Chien, Schenectady, N. Y.
Furukawa, Kozo, New York, N. Y.
Gentry, Byron W., New York, N. Y.
Gray, Newman D., Hazelton, Pa.
Hall, Clarence, St. Louis, Mo.
Harris, George W., Syracuse, N. Y.
Hayes, John J., Seattle, Wash.
Heatherington, Elmer S., Pittsfield, Mass.
Hiteshue, George P., Jeanette, Pa.
Hoffmann, Harry J., Boston, Mass.
Jackson, Alexander N., Salt Lake City, Utah
Johnson, Emil W., (Member), Grand Forks, N. Dakota
Johnson, Fredolph P., New York, N. Y.
Jons, Hugo, Chicago, Ill.
Keener, Charles A., Urbana, Ill.
Kerr, Thomas B., Peterboro, Ont.
Krausnick, Walter, Newark, N. J.
Lehmann, George F., Baltimore, Md.
Lukens, Arthur T., Philadelphia, Pa.
Marstall, Frank J., Pittsburgh, Pa.
Miller, Wayne W., Philadelphia, Pa.
Minnich, Charles T., Los Angeles, Cal.
Mougey, Wilbur E., New York, N. Y.
Mueller, Frank R., Washington, D. C.
Mumma, Levi B., Harlan, Ind.,
McKeeny, V. S., (Member), Seattle, Wash.
McLeod, Abner A., Worcester, Mass.
Merrill, Warren C., San Francisco, Cal.
NePage, J. F., (Member), Seattle, Wash.
Norby, Walter L., Worcester, Mass.
Palmer, Guy H., Schenectady, N. Y.
Peacock, Worth C., Sebring, Fla.
Pearce, Thomas C., Washington, D. C.
Phillips, Emory B., Brooklyn, N. Y.
Prendergast, Ralph M., Belleville, Ont.
Reynolds, L. Houston, Acme, N. C.
Rooney, William J., (Member), Washington, D. C.
Schleigh, George H., Jr., Pittsburgh, Pa.
Schmidt, William S., Johnstown, Pa.
Scott, Kenneth L., Madison, Wis.
Shen, Show-liang, New York, N. Y.
Sieurin, Alf. E., Worcester, Mass.
Singer, Emanuel, New York, N. Y.
Slater, Earl A., E. Pittsburgh, Pa.
Sleeper, Harvey P., E. Pittsburgh, Pa.
Spraragen, Benjamin, Warwick, N. Y.
Stephenson, John G., Peterboro, Ont.
Suransky, Paul, San Francisco, Cal.
Swezey, Burdette S., New York, N. Y.
Talla, Joseph, Phoenix, Ariz.
Tomlin, Amos C., Worcester, Mass.
Torner, J. V. H., (Member), Mt. Vernon, Iowa
Turner, Donald L., Takoma, D. C.
Van Dusen, Charles T., Wilmington, Vt.
Vincent, Gilbert I., Syracuse, N. Y.
Walker, Lewis B., Schenectady, N. Y.
Walker, Harold N., (Member), Seattle, Wash.
Walter, Otto W., Norman, Okla.
Watkins, Ira B., Norman, Okla.
Watkins, Murdock M., Birmingham, Ala.
Wickert, Leland A., Lancaster, Pa.
Wilbraham, Rossiter W., (Member), Philadelphia, Pa.
Williams, Fred M., Chicago, Ill.
Wise, John E., Madison, Wis.
Wright, Clyde G., Connellsville, Pa.
Wurth, Carl W., Bloomfield, N. J.
Total 87.

Foreign

Balsara, Jalejar N., Mazagaon, Bombay, India
Barringer, Edwin W., Hawers, N. Z.
Bennett, P. M., (Member), Santiago, Chile
Borel, Arnold, (Member), Cortaillod, Switzerland
Burrowes, Clement, Christchurch, N. Z.
Knowles, Everett H., Chuquicamata, Chile, S. A.
Messent, Keith S., Rugby, Eng.
Robineau, Raphael H., Santiago, Chile, S. A.
Seitanides, George B., Constantinople, Turkey
Swaney, James W., Lake Coleridge, N. Z.
Thomson, A., Christchurch, N. Z.
Wear, Ralph H., Christchurch, N. Z.
White, Charles F. H., N. Woolwich, London, Eng.
Yamada, Yasutaro, Tokyo, Japan
Total 14.

STUDENTS ENROLLED OCTOBER 14, 1921

13549 Pilcher, Ernest G., New York Electrical School
13550 Schoenfeld, Kurt, New York Electrical School
13551 Mauney, Carl G., University of North Carolina
13552 Hyde, William W., Tri-State College
13553 Mylerly, James G., Bucknell University
13554 Decker, Blair L., Ohio Northern Univ.
13555 Hug, William S., Carnegie Inst. of Tech.
13556 Martin, Paul S., Worcester Poly. Inst.
13557 Wallisch, Cyril J., School of Engineering of Milwaukee
13558 Heineck, Albert H., Worcester Poly. Inst.
13559 Gourley, Thomas S., Spring Garden Inst.
13560 Clarkson, Charles N., Worcester Poly. Inst.
13561 Centeno, Jose G., Columbia University
13562 Davis, Dean H., University of Alabama
13563 Ritchie, R. Morris, Kansas State Agri. Coll.
13564 Lainhart, Vaughn R., New York Electrical School
13565 Hubbard, Frank A., Pennsylvania State College
13566 Hoffman, Raymond H., Pennsylvania State College
13567 Houser, Kenneth O., Kansas State Agricultural College
13568 Meyer, George A., Kansas State Agri. Coll.
13569 Barrington, Clarence R., Worcester Polytechnic Institute
13570 Maust, Charles I., Drexel Institute
13571 Needham, Charles H., Worcester Poly. Inst.
13572 Chen, Pao-cheng, Worcester Poly. Inst.
13573 Corby, D. K., Kansas State Agricultural College
13574 Wurst, Leroy L., Kansas State Agri. Coll.
13573 Kibler, Ray S., Kansas State Agri. Coll.
13576 Hopkins, Harold D., Kansas State Agr. Coll.
13577 Miller, J. M., Kansas State Agri. Coll.
13578 Brigham, Alden I., Worcester Poly. Inst.
13579 Smith, Lester D., Newark Technical Sch.
13580 Ladner, Henry Brooklyn Poly. Inst.
13581 Norwig, John, Jr., Brooklyn, Poly. Inst.
13582 Shaw, Bernard C., Worcester Poly. Inst.
13583 Tustison, Joe G., Kansas State Agr. Coll.
13584 Downing, Lloyd H., Kansas State Agr. Coll.
13585 Aydelotte, Oscar H., Kansas State Agricultural College
13586 Means, Lester H., Kansas State Agr. Coll.
13587 Hershey, Perry J., Kansas State Agri. Coll.
13588 Field, Russell M., Worcester Poly. Inst.
13589 Watts, Thomas R., University of Cincinnati
13590 Wass, Donald E., Purdue University
13591 McPherson, Charles G., Kansas State Agricultural College
13592 Nass, Vincent W., Kansas State Agr. Coll.
13593 Ebenstein, Charles S., Kansas State Agricultural College
13594 Antle, Clifford L., Kansas State Agri. Coll.
13595 Cone, James H., Ohio Northern Univ.
13596 Maslin, Albert J., University of Michigan
13597 Wines, William B., Univ. of Michigan
13598 Dudley, Wilton R., University of Michigan
13599 Orr, Howard E., University of Michigan
13600 Carlton, Frank H., University of Michigan
13601 Olds, Richard N., University of Michigan
13602 O'Mara, Bermer J., University of Michigan
13603 Goodman, Henry W., Univ. of Michigan
13604 Seeley, Howard B., University of Michigan
13605 Quail, Kenneth H., University of Michigan
13606 Dreiss, William J., University of Michigan
13607 Shaw, Howard D., University of Michigan
13608 Gibford, Charles W., Univ. of Michigan
13609 McKie, Walter G., University of Michigan
13610 Wolfe, Richard C., University of Michigan
13611 Earhart, Edward C., Univ. of Michigan
13612 Champe, Willard, University of Michigan
13613 Bartley, Elmer D., University of Michigan
13614 Ewing, Ross, University of Michigan
13615 Kuhl, Clifford P., University of Michigan
13616 Fetters, Arthur S., University of Michigan
13617 Life, Harold G., University of Michigan
13618 Arguelles, Camilo R., Univ. of Michigan
13619 Seidman, Stanley M., Univ. of Michigan
13620 Kille, Lindley A., Ohio Northern Univ.
13621 Hyde, Merritt A., Jr., Case Sch. App. Sci.
13622 Durst, Stanley M., University of Illinois
13623 Deardorff, Harold E., Univ. of Cincinnati
13624 Chand, Dhir R., University of Illinois
13625 Riechart, Russell C., Cornell University
13626 Gray, Ralph C., Cornell University
13627 Cook, Junius F., Cornell University
13628 Austin, James A., Cornell University
13629 Maurer, Marie-Th., Cornell University
13630 Manchee, Alleyne W., Cornell University
13631 Yu, Chien-Loh, Cornell University
13632 Nih, Tsin, Cornell University
13633 Sovocool Stanley M., Cornell University
13634 Gillespie, Frank A., Jr., Kansas State Agricultural College
13635 Crall, Earle H., Kansas State Agri. Coll.
13636 Wood, Orwin C., Kansas State Agri. Coll.
13637 Engstrom, Olle D., Brooklyn Poly. Inst.
13638 Stohr, Frank H., State Univ. of Iowa
13639 Ryan, Eugene A., Syracuse University
13640 Baxter, Donald L., Syracuse University
13641 Adams, William, Syracuse University
13642 Angwin, Lester E., Syracuse University
13643 Maunder, Sydney T., Syracuse University
13644 Ryan, George S., Worcester Poly. Inst.
13645 Hoff, Carl J. R., Univ. of Wisconsin
13646 Koechling, Charles D., Brown University
13647 Bergstrom, Arthur G., Montana State Coll.
13648 Dailey, Charles O., Kansas State Agr. Coll
13649 Bjornson, Bjorn G., University of Wis.
13650 Jobe, C. Louis, Kansas State Agri. Coll.
13651 Holzer, Arval E., Kansas State Agri. Coll.
13652 Means, Lloyd E., Kansas State Agri. Coll.
13653 Barber, Galen A., Kansas State Agri. Coll.
13654 Addison, Griffith T., Univ. of Cincinnati
13655 Pingon, Andre C., Univ. of Cincinnati
13656 Arnold, George M., Univ. of Cincinnati
13657 Schneider, Matthew S., Univ. of Cincinnati
13658 Klopp, Norman F., Univ. of Cincinnati
13659 Petree, J. R., Univ. of Cincinnati
13660 Neuzel, Elmer F., Univ. of Cincinnati
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13668 Martin, Howard L., Univ. of Oklahoma
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13672 Thornton, Ralph E., Univ. of Oklahoma
13673 Tims, Vergil E., Univ. of Oklahoma
13674 Persons, George A., Univ. of Washington
13675 Merriam, Calri V., Univ. of Washington
13676 Keene, Elmer L., Univ. of Washington
13677 Wilson, J. V., Univ. of Washington
13678 Sandt, Kenneth E., Lafayette College
13679 Schug, Howard L., Lafayette College
13680 Grimshaw, Herbert R., Brown University
13681 Schoenfeld, Lester W., Lehigh University
13682 Ross, Robert O., University of Colorado
13683 Sutherland, John I., Univ. of Colorado
13684 Lehman, Lyle G., University of Colorado
13685 Hensley, Fred C., University of California
Total 137

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A complete list of the 42 Sections of the Institute, with the names of the chairmen and secretaries, may be found in the September issue of the JOURNAL and will be published again in the December issue. A list of the 61 Branches will be published in the December issue.

ADDRESSES FOR 1922 YEAR BOOK.

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It will be appreciated if those members who are not certain that they have notified Institute headquarters of any change in business or mailing address made during the present year, will submit the information called for below at the earliest possible date.

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Secretary

Title or occupation ....

Company or business address ....

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Panama	R. D. Prescott	M. P. Benninger, Box 174, Balboa Heights, C. Z.
Philadelphia	P. H. Chase	R. B. Mateer, Phila. Elec. Co., 1000 Chestnut St., Philadelphia, Pa.
Pittsburgh	H. W. Smith	E. C. Stone, Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.
Pittsfield	I. H. Sclater	A. C. Stevens, General Electric Co., Pittsfield, Mass.
Portland, Ore.	W. C. Heston	D. W. Proebstel, Portland Ry Lt. & Pr. Co., Portland, Ore.
Providence	Nicholas Stahl	F. N. Tompkins, Brown Univ., Providence, R. I.
Rochester	Sidney Alling	A. M. Stetler, Aluminum Co. of America, Granite Bldg., Rochester, N. Y.
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San Francisco	W. P. L'Hommedieu	A. G. Jones, 809 Rialto Bldg., San Francisco, Cal.
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Seattle	J. P. Growdon	E. S. Code, 1400 Alaska Bldg., Seattle, Wash.
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Toledo		Max Neuber, 1257 Fernwood Ave., Toledo, O.
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Urbana	E. H. Waldo	H. A. Brown, Univ. of Illinois, Urbana, Ill.
Utah	P. P. Ashworth	C. R. Higson, Utah Power & Light Co., Salt Lake City, Utah
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Total 42		

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Kansas, Univ. of, Lawrence, Kans.	E. S. Miner	C. A. Harris
Kentucky, Univ. of, Lexington, Ky.	T. M. Riley	R. H. Craig
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JOURNAL
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World Communication

BY ALFRED N. GOLDSMITH

Director, Research Department, Radio Corporation of America

IT is not intended, in this brief presentation of the broad outlines of the important subject of world communication, to do more than touch on the technical methods whereby communication is now being carried on or by which it is expected that communication will be carried on in the future. The subject matter is altogether too voluminous to permit more than a very general summary of the methods now in vogue or to be expected, and the setting forth of a general perspective of the problems involved and their relations. The writer must also indicate that his special interest in the field of radio communication has caused him to lay the main emphasis in this paper thereon, although, in a perfectly balanced paper on local and long-distance communication, the major portion would certainly deal with wire communication. While the writer has endeavored to minimize this lack of proportion in the paper, the reader is nevertheless advised to regard the paper as generally descriptive of the topics treated, but he should not judge the relative importance of the types of communication considered as proportionate to the space devoted to them.

Before proceeding further, the writer takes pleasure in acknowledging his indebtedness to Messrs. John L. Merrill and B. H. Reynolds of All America Cables, Incorporated, to Mr. A. H. Griswold, and Mr. O. B. Blackwell of the American Telephone and Telegraph Company, to Mr. Donald McNicol, to Messrs. C. H. Taylor, W. A. Graham, W. A. Winterbottom, P. Boucheron of the Radio Corporation of America, and to Mr. C. M. Yorke of the Western Union Telegraph Company, for the illustrations, information, and advice which they have so kindly furnished in connection with the preparation of this paper.

It must doubtless have occurred to every person who carries on business of importance, and indeed even to that ubiquitous individual, "the man on the street," that communication by direct transportation of the communicant is a most clumsy though necessary method. The carriage of the ponderous bulk of the human body from one point to another, merely to enable word-of-mouth communication, is doubtless an ineluctable necessity in many cases at present, and yet it is far from satisfactory. What is desired is the communication of intelligence, not the painfully long and tedious motion of the individual in whom the intelligence is embodied. To be sure, ordinary speech from man to man is a form of communication which, within a restricted range and for a given tongue, meets all ordinary requirements. But it becomes unsatisfactory as soon as we become removed from anyone to whom we wish to transmit our ideas. What we all desire is means so that we can get into immediate touch with all of those with whom we do business or with whom we take our pleasures. Our interest in communication then, is roughly dependent on the distribution of these people. Evidently we are the most interested then in transmission within a comparatively restricted area. In view, however, of the wide range of modern business and the widening range of personal travel, long-distance communication has also become of great interest to us.

It will be found that there are two well-defined methods of communication, each having its particular characteristics. Broadly, these may be termed "guided communication" and unguided communication." Ordinary speech, (unless it is particularly closely directed by a megaphone) is of the unguided variety. In other words, the energy radiated passes out freely in *all* directions enabling any one on the surface of a sphere, having the supposed aerially suspended speaker at its center, to hear, that is, to receive the messages equally well. As a general rule, methods of communication utilizing free wave transmission are entirely unguided, partly because of the difficulty of radiating a sharply defined stream or "searchlight beam" of radiation and partly because of the difficulty of preventing its subsequent diffusion or spreading in all directions through diffraction, refraction, reflection, and passage through diffusing media (for example, fog). As already hinted, the best rough approximation to a directed beam based on free wave propagation is the modern searchlight, which has indeed been used for military signaling and for light telegraphy and light telephony (photophone transmission). In no

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case of communication by free electromagnetic waves do we find anything like the definiteness of destinations and number of parallel channels which are achieved in wire communication, where we have remarkable results in the compression of a great number of separate telephone conversations within the same cable sheath.

Ordinary telephony and telegraphy, and "guided radio," "wired wireless," or "carrier current telephony and telegraphy," (as it is variously called) are all good examples of guided forms of communication. Here we have electromagnetic waves very closely guided in and by material conductors (wires) to a definite point of destination, and without sidewise radiation of the lengthwise propagated energy except where the distributed line constants suffer abrupt change.

Both guided and unguided electromagnetic communication depend on the transmission of electromagnetic waves through space. In unguided transs mission, which is generally known as radio, the wavespread out over a wide area and in this way may be picked up by a large number of receiving stations. In guided communication, generally known as wire transmission, the conducting wires form, as it were, electrical paths, which guide the waves to the exact point to which it is desired to send them.

Both of these methods have their advantages and disadvantages. In general they are not competitors of each other for overland working but supplement each other.

Modern radio communication is unguided, and hence can be received equally well at all points equidistant from the transmitting station. Here and there partially directed radio beams have been produced, principally for military purposes or for harbor radio beacons or the like. There are distinct possibilities of future developments along this line of directional radio transmission, naturally, by preference on the shorter wave lengths and over the shorter distances, though again within the limits imposed by the mechanism of wave radiation and propagation and in no case approximating even roughly to what can be accomplished by wire methods.

Guided communication differs from the unguided methods in that the signaling energy is directed along a well-defined path terminating, as a general rule, exclusively at the true recipient of the message. Of course, the true recipient of a *telegraph* message is the final receiving operator; the person to whom it is addressed receives only a letter transcript of the message, carried to him by a low-speed projectile method of communication, namely a messenger boy. But between the sending and the receiving operator on a metallic-return buried-cable telegraph circuit there exists what is to all intents and purposes a unique and completely definite path. In strictest accuracy this statement would have to be modified because of the leakage of current from telegraph conductors, the induction of currents in nearby conductors even from circuits made up of twisted pairs of conductors, and the radiation of electromagnetic waves from a telegraph circuit during the transient conditions. Most of these effects are, in general, inappreciable and may be neglected for the moment, although their effects in long telephone circuits require careful consideration.

It appears that both guided and unguided communications have noteworthy characteristics and real spheres of usefulness. The advantages of guided communication are the much greater ease of securing secrecy of communication and freedom from "tapping," the higher efficiency of energy transmission, the definite and known nature of the destination of the message, and the comparative ease of establishment of a compact many-channeled communication network.

It is interesting to note that the *efficiency of energy transmission* by unguided systems of communication is practically nil. The approximate ratio of radiated power to receive power for fair transoceanic communication via radio is of the order of one hundred trillions to one. And by no means all of the power available in the antenna or radiating system of the transmitter is actually radiated. The efficiency of the mere act of radiation may be from roughly 50 per cent down to a per cent or two. The efficiency of transmission of energy over even a long telephone circuit or submarine cable is incomparably greater than the value given for unguided communication having a highly disadvantageous law of attenuation or diminution of signal amplitude with distance. Nevertheless, the *efficiency of communication* may be very high for unguided signaling, both as a system for transmitting intelligence and as an economical means for such transmission. Thus, the cost of accurately sending a message across the ocean via radio compares very favorably with the cost of transmission by submarine cable. That is, there is an approximate balance between the high cost of the long submarine cable and its comparatively inexpensive terminal stations and the high cost of the radio transmitting station, the low cost of the radio receiving station, and the zero cost of the medium of transmission. The balance is such as to indicate that the question of the intrinsic efficiency of energy transmission does not properly enter into a consideration of the real value of a communication system. It must not be inferred that the efficiency of energy transmission is without importance in comparing different types or systems of unguided communication with each other but only that it is not a suitable criterion for judging the commercial usefulness of an unguided system of communication as compared with a guided system.

It appears that unguided communications, such as radio, are preeminently fitted for broadcast service and will find a wide application in this direction. At

present both the United States and Germany are using radio for the dissemination of information, and practically all the larger countries use it for broadcasting time signals, hydrographic information and the like.

The principal problems connected with radio communication, selected as a typical and effective form of unguided communication, are those connected with the avoidance of atmospheric disturbances of reception and those connected with the mutual interference of various transmitting stations.

It appears that there originate in the atmosphere, in a fashion not entirely understood, a number of forms of electric disturbances which tend to interfere with radio signals. Under favorable conditions, and with the most modern forms of receiver for eliminating such disturbances, their presence would hardly be suspected; on the other hand, in the middle of a lightning storm in the vicinity and with unsuitable receivers, all communication will be interrupted. As a result of determined research, there have been produced forms of receivers which markedly reduce the effect of such electric strays, and enable good communication to be fairly continuously maintained. It is to be expected that the normal further evolution of radio receivers, the increase in transmitter power, and the skilful handling of traffic will lead to *continuous* commerical communication regardless of these undesired intruders.

The use of the ether as a common channel for all radio messages is not an unmixed blessing. At times it leads to situations paralleling those encountered by the urban dweller who has many musically inclined neighbors, all of whom simultaneously persist in utilizing the available air for powerful acoustic radiation. The gratification of the listener is markedly diminished under such conditions of "interference" or "jamming" as it is termed by the radio operator. Monofrequent radiation and audio-frequency selectivity suggest themselves as the first type of solution in the acoustic case mentioned. For radio communication, we have aimed at as nearly monofrequent or "monochromatic" radiation as possible from the transmitting station, and the use of radio-frequency selection at the receiving station. This method is, on the whole, very effective and enables a considerable number of mutually non-interfering radio channels to be in simultaneous operation. In addition to frequency selection, in its several most recent forms, we have available directional selection. This latter involves the use of special antenna systems at the receiving station which respond most powerfully to signals coming from one or more directions. While the development of directional reception is still in its earlier stages, it is possible to reduce interference considerably by this means. Directional reception has other practically useful applications in the guiding of ships in times of fog or storm, using either the "radio compass" or the "radio beacon." In the former case, the directional receiver is located on land, and the ship is located during its transmission by triangulation between two or more land stations. In the latter case, the directional receiver is on the ship and its location is determined by triangulation on board ship after finding the bearing of two or more known land "beacon" stations which send out their indentification signals more or less steadily.

The establishment of the radio analog of "order wire circuits" is entirely possible, and leads to no particular difficulties. On the other hand, the development of effective radio ringing methods, which enable dispensing with the constant attendance of an operator, for example on board ship, is still in its earlier stages. This is not a serious drawback at present since the transoceanic circuits run nearly continuously and therefore require the constant attendance of operators in any case, and in the marine service it is very desirable to have an operator on duty at all times to pick up faint distress calls and hydrographic information (storm warnings and the like). However, the development of effective and reliable call signal systems may become of more importance for unguided communications as time goes on.

While two-way communication is readily possible through direct speech, that is, by the use of unguided air waves, true duplex communication is not so easily obtained. The essential element in full duplex communication is that there shall be two streams of signals flowing in opposite directions simultaneously and without mutual interference. Thus there are required two transmitters and two receivers, which influence each other only in pairs. In radio communication, full duplex communication is readily obtained and is, in fact, used largely in the transoceanic service. In the marine services, on the other hand, the users are generally content with two-way communication wherein the two parties to the communication take turns at sending and receiving alternately. The traffic-carrying capacity of a circuit is more than doubled by the substitution of full duplex for two-way service since the correction of errors is then more readily effected without delay and the coordination of traffic on both sides more easily carried out. It is interesting to note that not only duplex but even multiplex radio communication is possible on a single frequency or wave length by the use of audio or superaudio frequency modulation. That is, continuous waves of a certain length are modulated or controlled at a frequency lower than the wave frequency and the reception is accomplished with double selectivity; namely, an initial selectivity to the actual wave frequency followed by a selectivity toward the lower or modulation frequency. By thus building a lock which requires the simultaneous use of two keys to open it, we can increase the selectivity of receiving stations. It is not believed, however, that the ultimate total traffic-carrying capacity of the ether is increased in

this way, even though it avoids admirably certain present-day difficulties and has a real sphere of usefulness.

If we revert to the broadest aspects of the problems of world communication, we find that an ideal system can be imagined which would presumably meet all reasonable requirements. This would be a continuously operative interference-free person-to-person network. It should include every person on the globe and clearly carry speech, which, it is hoped, would be in some lingua franca or universal language. Thus baldly stated, the problem seems frankly insoluble in terms of agencies now available. Yet it is not difficult to imagine equivalent systems which would constitute something better than a first approximation to this remarkable plan. Let us imagine a very large number of telephone substations located at all convenient points. Most of these substations will be fixed, and connected by wire line to the central stations or exchanges. However, there may be in addition movable substations which will, of course, be generally connected by radio

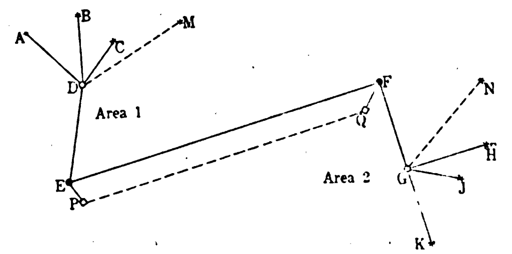

FIG. 1—SCHEMATIC COMMUNICATION NETWORK EMBRACING WIRE AND RADIO SYSTEMS

to the central offices. As examples of such movable substations we may take ships, railroad trains, and aircraft equipped with radio telephone sets, or in special cases individuals supplied with highly portable radio telephone outfits. We may expect that even individuals, such as forest rangers and other groups of professional patrolmen, would make good use of such portable substation equipment. The central offices will be connected with each other, directly or indirectly, by wire systems where wires can be more effectively and economically maintained, and by radio where wires cannot be maintained. In Fig. 1 is shown schematically the layout of such a system including, however, only two of the communication areas.

We will suppose that person A in area 1 desires to speak to person H in area 2. Substation A is connected by wire to central office D of area 1. Thence the speech currents travel to the "long-distance" exchange at E. From E the speech travels by wire or radio to F, the "long-distance" exchange nearest to G, the central office of area 2. If the radio route is used, the radio stations P and Q, controlled by E and F respectively are employed. After passing to G, the speech is sent directly to H, the called station. At various points along their path, the speech currents are amplified as necessary. In case a movable substation desires to share the facilities of such a communication system, it will do so by establishing radio telephone communication with a radio station at the local central office or a radio station directly connected thereto. Thus if an occupant of the railroad train M provided with a radio telephone set, desires to use the telephone system shown, he does so by establishing communication with D by radio. A movable substation at N could similarly share the benefits of the system by connecting with central office G by radio. So that we can even imagine direct communication between stations M and N, both in motion, through this communication plan. It will be seen that communication with moving substations, and telephone communication across oceans, will probably be on a radio basis in this system, and that all the remaining portions of the communication (which constitute the major portion of the communication network in practically all cases) will be by wire. The particular system described illustrates the judicious and useful combination of guided and unguided systems of communication, though it represents an extreme case and a very small percentage of the total telephone traffic handled.

The great bulk of communication is now carried on by wire methods. There is no question but that wire transmission must always carry the great bulk of communications, particularly in the well settled and highly developed parts of the world where its methods permit the setting up of reliable and economical paths for carrying tremendous numbers of messages without mutual interference.

Radio, however, has an important field to fill, as an auxiliary of the wire system in extending service to ships at sea, to aeroplanes, perhaps even to automobiles, and in general to moving bodies to which wires cannot be connected. It has a pioneering field in undeveloped countries, or wherever natural barriers make it difficult to set up the wire system. It has perhaps its most profitable and commercially useful field in giving service between continents separated by wide reaches of ocean.

The possibilities of guided transmission can be well illustrated by two examples: First, the transcontinental line between New York and San Francisco, which is today giving high-grade commercial service between the cities of our eastern and western coasts. The second is the 1200 pair subscribers' cables, now being placed by the telephone companies, which permit of 1200 simultaneous conversations being transmitted through a sheath of less than 2.5 inches, inside diameter.

Two other illustrations which will likewise indicate the possibilities of radio are: First, the radio telegraph service from the eastern coast of this country to all of the countries in Europe. Second, the radio broadcasting stations, which have been set up and which permit all of those within range of these broadcasting

stations who have the necessary apparatus to pick up the news and entertainment which is sent out from the stations.

For the case of long-distance wire communication in certain of the more important countries, such systems as those required in the previous plan already exist to a considerable extent. For the corresponding inter-

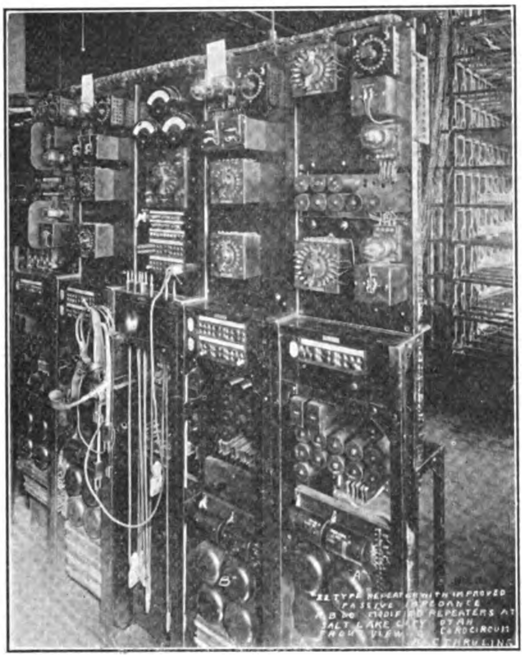

Fig. 2—Long-Distance Line Telephone Repeater Installation A. T. & T. Co., Salt Lake City, Utah

national transoceanic network, involving radio telephone trunk circuits, the surface has not yet been scratched, although the recent remarkable demonstrations by the American Telephone and Telegraph Company of telephone service from Catalina Island to Havana indicate the extent to which this problem is engaging the attention of investigators and firing the imagination of far-seeing executives of communication companies. In the case mentioned, telephone communication was established between two points thousand of miles apart, separated by portions of two oceans, and across a continent. The speech was sent from Catalina Island across a stretch of the Pacific Ocean via radio, thence by wire line across the United States and down to Key West, Florida, and finally through the submarine telephone cable to Havana. The transmission difficulties were equal to those in bridging the stretch from London to Pekin, or from New York to Buenos Aires, as pointed out by Dr. J. J. Carty. It is likely that for a long time mankind will find that a very approximate approach to the system of world communication previously described will satisfy the most ambitious engineers and traffic experts. The omission of the portable substations *M* and *N* would work no great hardship at this time, particularly if the number of conveniently located substations such as *A*, *B*, *C*, and so on is continually increased into a practically all-embracing system.

The subscribers' local telephone stations (such as *B* and *J* of Fig. 1) already exist to a considerable extent in some parts of the world. Thus in the United States, there are 12,600,000 stations of this type in existence, interconnected by 25,400,000 miles of wire, and carrying more than eleven billion messages annually. This is one telephone per nine persons of the population, roughly, and approximately four telephones per square mile for the entire area of the country including its uninhabitable portions. Obviously we are approaching an era of truly universal communication service, when a modern country can show a telephone network such as that of the Bell Telephone System connecting over 70,000 cities, towns and rural communities. Some of the component elements of such a vast communication system deserve attention. Starting from long-distance exchanges, such as that in New York, the lines radiate in all directions. Careful "loading" of the lines prevents distortion of the speech. At intervals the attentuated line currents are automatically amplified in "repeater stations," such as that at Salt Lake City shown in Fig. 2. These land line circuits may be automatically extended through submarine telephone cables. Or radio telephone transmitters

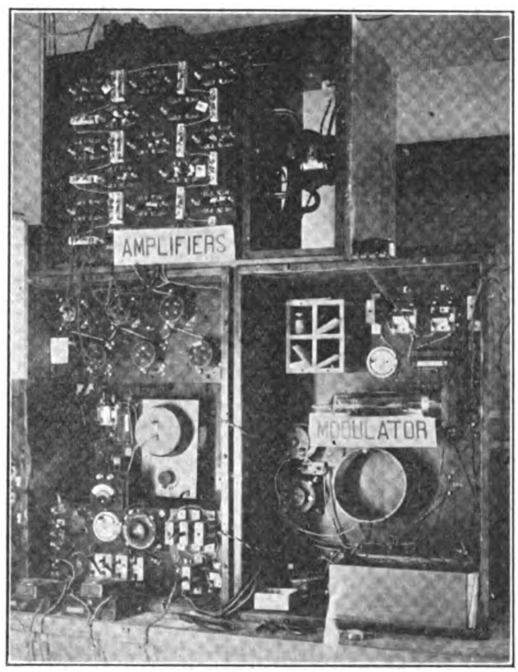

Fig. 3—Amplifier and Modulator Equipment of Radio Telephone Station, Arlington, Va.

may be used as extensions of the land line system. Thus Catalina Island is connected to the California mainland and the Bell telephone system through a radio telephone link. Not only is perfect duplex telephone service maintained over this combined wire and radio circuit, but the introduction of the radio portion of the circuit does not change even the details of handling

traffic. For instance, the circuit is so arranged that it is possible to "ring through" the radio portion for calling purposes as well as to talk over it! The amplifying and modulating equipment of a radio telephone transmitter at Arlington, Virginia, which carried speech transferred from the wire lines of the American Telephone and Telegraph Company to Hawaii and Paris, is shown in Fig. 3.

It is obvious that in the future, wire communication will be supplemented by radio communication; the wire system being used for local distribution and for long distances, save where large bodies of water, the mobile nature of the receiving station, natural barriers, or other special conditions obtain; and the radio system for the cases just mentioned and for broadcasting services.

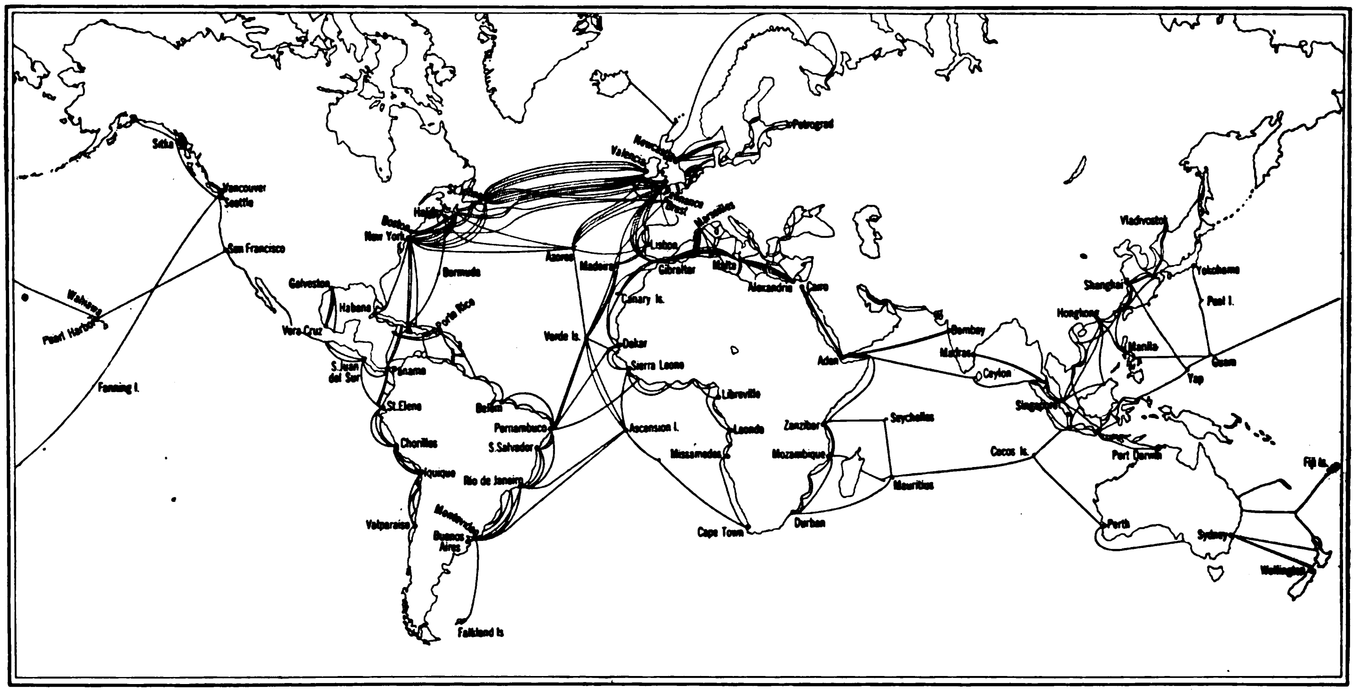

Fig. 4—Map of Present Submarine Telegraph Network of the World

The development of wire communication both in magnitude and quality has been one of the most remarkable achievements of pure science and technology in history, and this development is proceeding surely and rapidly to more useful stages. We need only consider briefly a few of the lines of modern endeavor in the field of wire communication to appreciate something of what the future has in store. By the use of modern multiconductor cables, storm-proof lines have become widely available and enable an immense number of messages to be carried simultaneously within the same cable sheath without mutual interference from each other. By methods of mutual interconnection (such as the so-called "phantom" circuits) each conductor may carry more than one message without interference. The use of carrier currents permits the further and wider utilization of conductors for a still greater number of independent channels. By "loading" the long lines suitably and providing them with vacuum-tube amplifiers or repeaters, the range of commercial transmission has been increased to a hitherto unbelievable extent. And the duties of the skilled operator are being handled more and more by highly ingenious automatic equipment. In telephony, machine switching is expected to replace largely the central operator, and in land line telegraphy, printing telegraph equipment is reducing the volume of manually transmitted and aurally received traffic.

The integration of wire and radio systems, at least from the operating standpoint, is one of the promising possibilities of the future. As has been indicated above, these systems are mutually supplementary and can best serve the public when each fulfills those duties for which it is most suited. So far as economic and service possibilites are concerned, the guided systems of wire communication promise the more important future developments in the field of normal overland communication, although there is no doubt that a valuable service of increasing magnitude will be furnished by radio communication. In the field of overseas communication, it is believed that for some time there will be a very helpful coordination of cable and radio communication to the advantage of each and with a resultant improved service to the public. There is probably no field where cooperation between the various agencies is more important than in the field of universal communication.

The cable network of the world, shown in Fig. 4, indicates that much has been achieved and that not

a little remains to be done before high-speed direct service from each country to every other shall be available. It will be noted that Europe and North America are the radiating centers of cable communication, and that the North Atlantic boasts the greatest number of transoceanic cables. There are, indeed, no less than seventeen such cables across the North Atlantic. On the other hand, South America, Africa, and Australia have a smaller number of cables and more indirect service. In the case of South America, this situation is being vigorously and markedly improved. While many of the cables have clearly been laid for commercial use and financial profit, others have apparently been laid for military or strategic reasons. A close study of the map and cable statistics will indicate the preeminence of England in this field of communication. This is partly a natural response to the needs of the far-flung British Empire, partly

FIG. 5—TRANSATLANTIC CABLE STATION BUILDING AT PENZANCE, ENGLAND

the result of early experience in the cable operating art, partly in consequence of the possession of an unusually ample supply of high-grade gutta-percha such as is used for cable insulation, and partly the just reward for foresight and planning of adequate communications. It is to be noted that the United States is rapidly forging ahead in the cable field, particularly in the improvement of communications of the Western hemisphere.

Some idea of the scope and methods of an extensive cable system can be gained from Figs. 5 and 6, which illustrate stations and apparatus of the Western Union Telegraph Company. It is in such distant outposts of civilization that the communication of the populous centers of the world is maintained. At such points, after a journey of thousands of miles beneath the ocean, the message finally actuates the delicate apparatus necessary for its recording and decipherment. The dignified and sturdy appearance of the buildings which house this apparatus is indicated by Fig. 5, showing the cable station at Penzance, England. Besides the actual transmitting and receiving apparatus, much auxiliary equipment properly finds its place

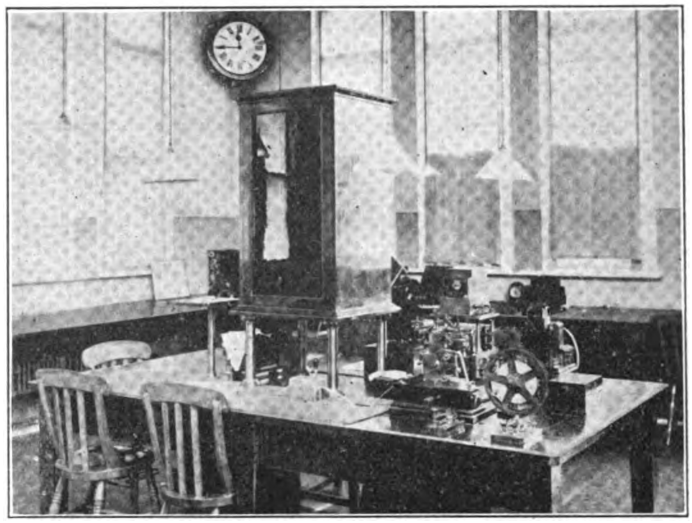

FIG. 6—MODERN TYPE OF SIPHON RECORDER USED IN CABLE TELEGRAPHY

in the modern cable station. An actual siphon recorder at Penzance, seen at close range in Fig. 6, illustrates the form of apparatus which draws, on the moving paper tape, the waving line from which the skilled operators translate the cable messages of the present day world.

As a further illustration of the latest methods of handling cable traffic, there is shown in Fig. 7 some equipment of the All America Cables, Incorporated. While the message is being sent, it is carefully checked

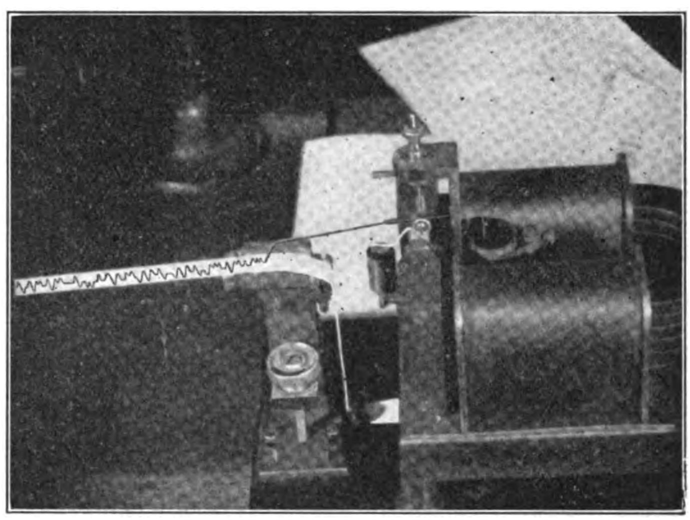

FIG. 7—"BABY" SIPHON RECORDER USED BY CENTRAL & SOUTH AMERICA TELEGRAPH COMPANY

by typewriting it from a tape record made by the "baby recorder" of Fig. 7. At the receiving station, the messages are recorded by the siphon recorder,

the waving line on the tape then passing before the receiving operators who again typewrite the message. When high-speed reception is practised, it becomes necessary to have several operators transcribing the tape from each recorder, and this is done by an ingenious system whereby each of the successive operators passes his "overflow" message to the next further operator.

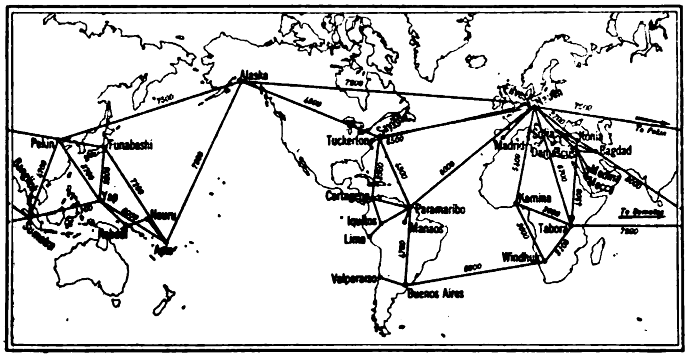

Fig. 8—German Scheme of 1913 for World Communication

Complicated as are the mechanical and electrical details of the apparatus used and prosaic as may be the daily routine of those who manipulate the apparatus, the dullest imagination cannot fail to perceive the underlying romance and inspiration of this quiet but powerful conquest of space, and none will fail to admire and praise the fortitude and vision of the early pioneers who made cable communication possible, and of their successors who have brought it to its present capabilities.

A number of world schemes of radio communication has also been proposed in the past, and some of them are in the process of present realization. The earliest one is shown in Fig. 8. (Here the distances are given in kilometers.) It represents the extremely ambitious

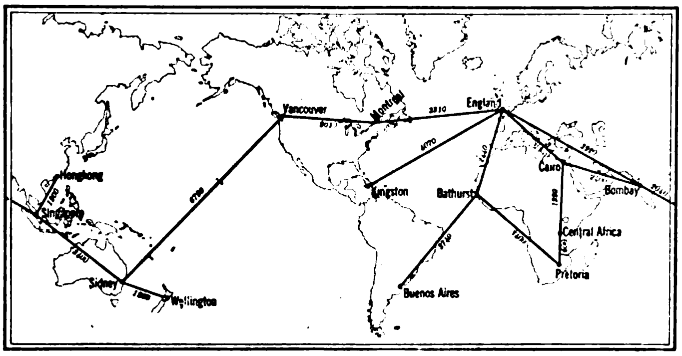

Fig. 9—British Imperial Communication Scheme of 1913

German scheme of 1913 and is clearly influenced to a great extent by military as well as commercial considerations. The length of some of the jumps from station to station, taking into consideration the transmitter powers and the types of receiving apparatus, then available, indicate that only partial or occasional service could have been expected over the longer spans, and then only at low speeds. It also appears that each station was to handle several channels and therefore presumably to divide its time between its various correspondent stations. This type of service is more suited to press and propaganda work and light traffic than it is to the more exacting high-speed commercial requirements. This plan was not carried far before the war brought about its complete destruction.

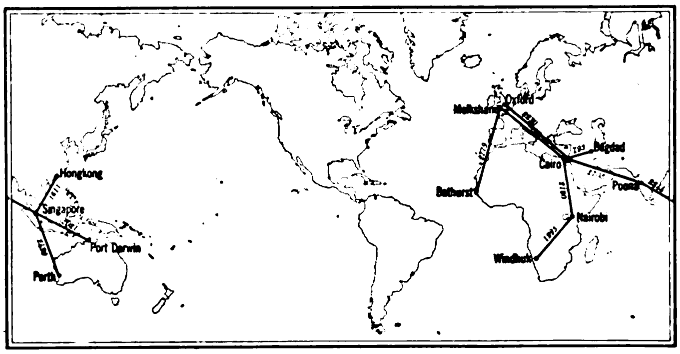

Fig. 10—British Imperial Scheme of 1919 for Radio Communication

Fig. 9 (on which the distances are in nautical miles) represents the first of the British Imperial schemes for radio communication, the so-called "All-Red Chain." It dates from 1913, and was the plan of the British Marconi Company which submitted it to the British Government for approval. It was adopted, and some work was done along the lines indicated when the war intervened. The changes caused by the war and other causes led to its discontinuance and to rather serious differences between the British Government and the Marconi Company. Afterwards the claims of the Marconi Company were in part allowed and suitable financial compensation paid by the British Government for the loss of the original contractual

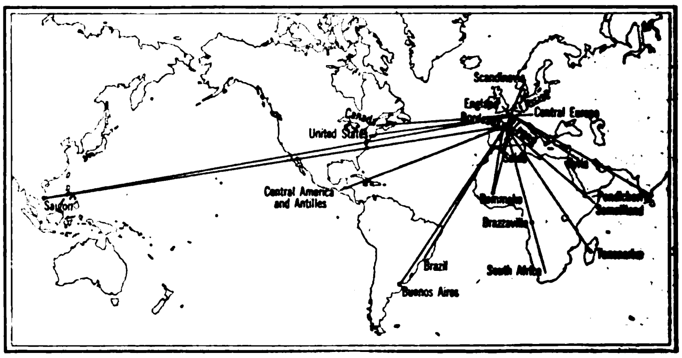

Fig. 11—French Communication Scheme

profits. The plan itself included two routes from England to Australia with only two relays. It was a scheme involving long spans. London was the main center from which most of the communication to distant points radiated directly.

In 1919 and 1920, a British Government Committee reconsidered the entire project of the Imperial

radio scheme, and recommended the less ambitious plan given in Fig. 10. Here the Western Hemisphere is apparently neglected, London is not connected directly (without relays) to the more distant points, the average span is shorter, and the terminal points chosen are dictated apparently only in part by commerical considerations. This system will be Government-owned and operated, which may account for the nature of this plan, which is now being carried out. Only a very small portion of this plan has been carried out so far.

Another very ambitious plan is due to France and is given in Fig. 11. It, too, is not planned entirely along commercial lines. Furthermore, it is clear that the French stations are intended to divide their time between a number of terminal stations and that extemely long spans are planned. Of the stations shown on the French plan, several are built and several more are in the process of construction. A considerable portion of this plan will, however, still have to be worked out in the future. It is noticeable that both the present French plan and the original German plan lay more stress on South American traffic than does the present British Imperial scheme.

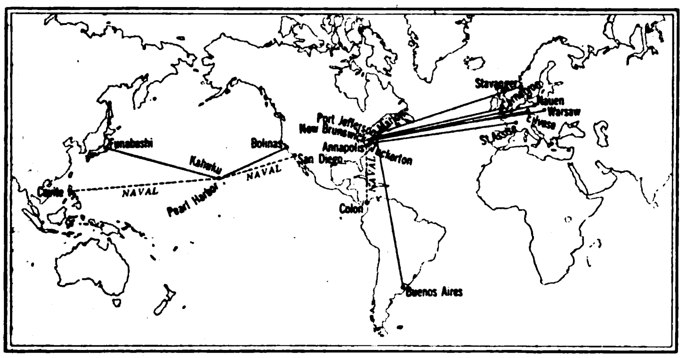

FIG. 12—COMMUNICATION SCHEME OF AMERICAN ORIGIN

The communication system shown in Fig. 12 is that of the United States and differs in several important respects from the preceding plans. In the first place, *every station* shown thereon is either in operation or under construction, and by far the greater portion of the stations are those already in operation. Furthermore, for the sake of clearness, the large contemplated expansions of this plan are not shown on the diagram although they will add nearly as many more channels of communication to the system as those already shown. In the second place, the plan shown is preeminently a commercial one, both in the placing of the terminal stations and in the practically exclusive use of each American station for a single channel. This latter feature permits the speedy handling of large volumes of traffic and avoids the troublesome delays which result when the time of a transmitting station is excessively "chopped up" or divided between too many receiving stations. The system is one of moderate and long spans, this being dictated to some extent by the geographical location of the United States, its particular communication needs, and the absence of American possessions at certain points. The needs of the United States, considering these circumstances, have very greatly stimulated the technical improvement of radio communication, and have led to the satisfactory solutions of the problems of long-distance radio communication. The case is an interesting illustration of the stimulating and helpful influence of natural obstacles.

It is hardly profitable, as matters now stand, to consider television and telestereotypy in connection with world communication. By television we mean the transference of an image or picture from one point to another other than by the use of light waves or the physical transportation of a material object. There are two general classes of television, the instantaneous and the deferred. In the case of the instantaneous type, the picture visible at the receiving end of the channel corresponds with that at the sending end practically at that moment. In general, such systems would be capable of producing moving pictures at the receiving end. There have been some partial approaches to this system for monochromatic pictures of simple objects such as could be readily synthesized from a comparatively small number of square picture elements of controllable luminosity. However, it is not worth speculating yet as to the practical value of such a system. In the deferred system, the picture is divided into dot or linear elements which are sequentially transmitted over the circuit with what is practically a simultaneous indication of their luminosity and with an appropriate means of synchronizing the receiving transcriber element motion to that of the transmitter element motion. In most of those systems, light-sensitive substances such as selenium form the basis of the process. Pictures can also be transmitted by dividing the entire picture into reasonably small elements and sending a code message systematically covering the brightness of each picture element. This is naturally a tedious procedure, and we are told that three hours were required for the transmission of a moderately complicated picture across the Atlantic by this method which, however, requires no special transmitting or receiving apparatus. Neglecting for the moment the broadcasting of the personal appearance of errant criminals, and certain military applications, there seems to be no great demand for television and it is not to be expected that its progress will be rapid. This is even more the case for telestereotypy or the reproduction of solid objects in their three dimensions at the receiving end. In fact, telestereotypy at present is purely an interesting problem for which a number of general plans of investigation have been suggested.

On the other hand, printing telegraphy is of more general interest. In the various printing (or writing) telegraph processes, special signals, other than the

usual Morse code signs, are sent over the wire or radio circuit, and, at the receiving stations, control the func-

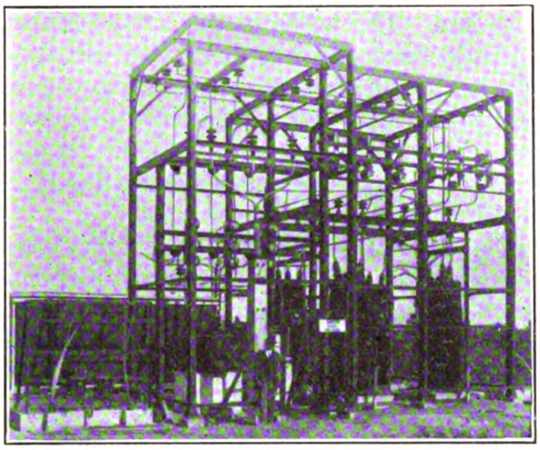

Fig. 13—Outdoor Substation at Radio Central, Long Island, N. Y.

tioning of an electrically operated typewriter or equivalent writing machine. In some cases, the material is printed on a continuous tape whereas in other cases the received signals are printed line by line on message blanks. In the latter form of so-called "page-printers," there are "line spacing" and "carriage return" signals which are sent at the correct times from the transmitter and which accomplish the corresponding results at the receiver. The transmission in the case of printing telegraph systems, and indeed of all high-speed systems, is from narrow paper tape which is perforated by hand or on a perforating typewriter and then run through a Wheatstone high-speed transmitter or a similar automatic transmitter. Provided care is taken in the perforation of the tape, the sending by this means is more uniform and reliable than with hand sending.

It has long been known that traffic from one country to another is by no means evenly distributed throughe out the twenty-four hours of the day, the days of the week, or the months of the year. There are very pro-

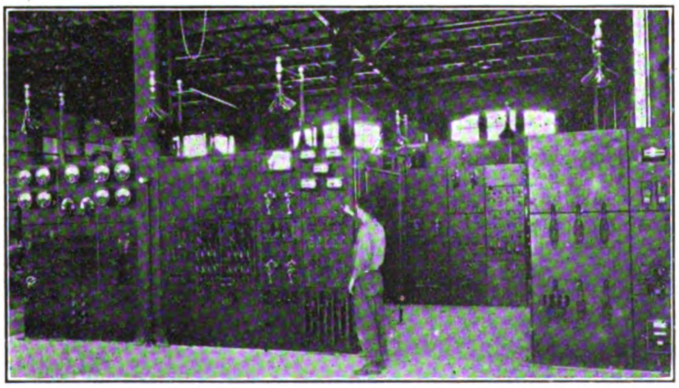

Fig. 14—Sections of Control Switchboards, Radio Central, Long Island, N. Y.

nounced peaks, and depressions or lulls of traffic found to exist. Thus, the traffic between two countries will generally be heaviest for the hours during which daylight is common to both, and will drop to a minimum during the week end. It would be desirable to handle the peak of the load without permitting traffic to pile up, but this may not always be feasible for reasons of

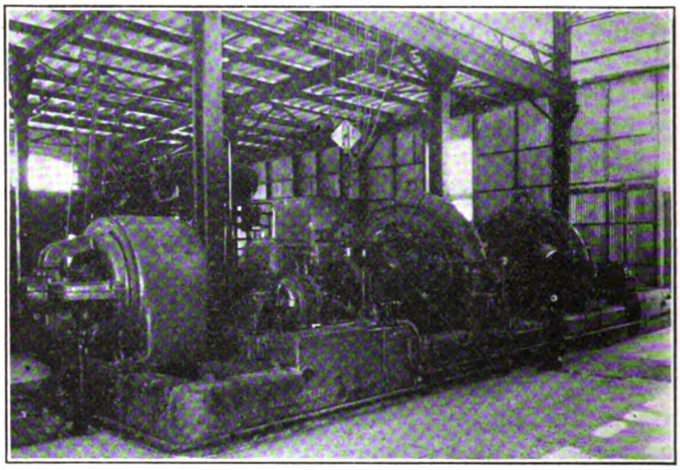

Fig. 15—Alexanderson Alternators Installed at Radio Central, Long Island, N. Y.

economy, both of equipment and of necessary personnel. This has led to the attempt to secure a high load factor for communication circuits by encouraging some of the users of the service to accept a certain delay in the delivery of their messages which are then sent at a reduced rate. Thus we find in addition to normal messages, which are sent in the order in which they are

Fig. 16—Land Line Telegraph Equipment Connected to Control Operation of High-Power Radio Transmitter

received the "deferred" messages which are sent at the earliest opportunity when traffic has slackened sufficiently to permit their introduction. "Night letters" and "week end letters" are sent during the periods indicated, and are obviously intended to fill an otherwise dull period in the circuit. On some circuits, "urgent" messages are accepted which take priority over all others, and require the payment of a considerably increased rate. As a general rule,

the minimum number of classes of messages required to maintain an acceptable load factor is desirable, not only because of the increased routine in handling traffic of many different classes but also because of the confusion in the public mind and the possible dissatisfaction which results when the type of service rendered in any given case is not clearly understood in advance.

A fairly definite idea of what is required for the transmission and reception of messages on a modern radio circuit can be gained from the following series of illustrations covering stations and equipment of the Radio Corporation of America. The power required to operate the great transmitters enters the station from an outdoor substation, such as that at the New York Radio Central on Long Island, shown in Fig. 13.

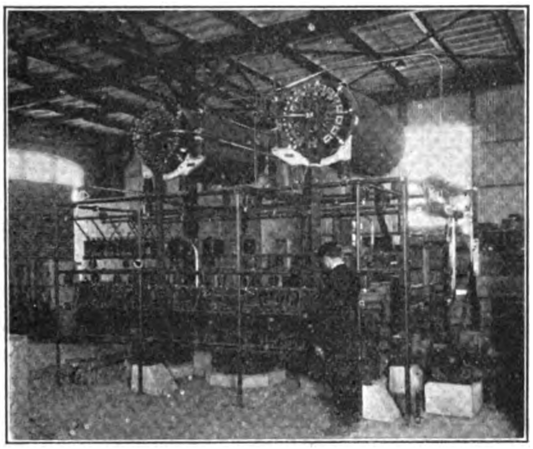

FIG. 17—MAGNETIC AMPLIFIER EQUIPMENT AT RADIO CENTRAL

Complicated switchboards, such as that shown in Fig. 14, enable the control of the many hundreds or even thousands of kilowatts required for the station. We then reach the heart of the transmitting station, namely, the radio-frequency generators which produce hundreds of kilowatts of very high-frequency energy. The two Alexanderson massive alternators already installed at the Radio Central are shown in Fig. 15. The machines represent years of research and development and are among the most remarkable products of modern engineering. The frequency of the currents produced by those in the illustration is no less than 20,000 cycles per second! To pass for a moment to the opposite type of equipment, there is shown in Fig. 16 some of the conventional telegraph equipment which controls a transmitting station when working at hand speed. When working at high speed, automatic transmitters controlled by perforated paper tape are employed.

It has always been a problem to control several hundred kilowatts of power at frequencies of 20,000 cycles per second by breaking it up into the dots and dashes of the Morse code at speeds as high as 100 words per minute or more. When it is considered that this is equivalent to starting and stopping the flow of power fifty times per second, accurately and faultlessly, and that the initial control power is merely the few watts that can be drawn from the terminals of a telegraph line, the magnitude of the problem becomes evident. By the development of high-speed power relays and the new "magnetic amplifier," the

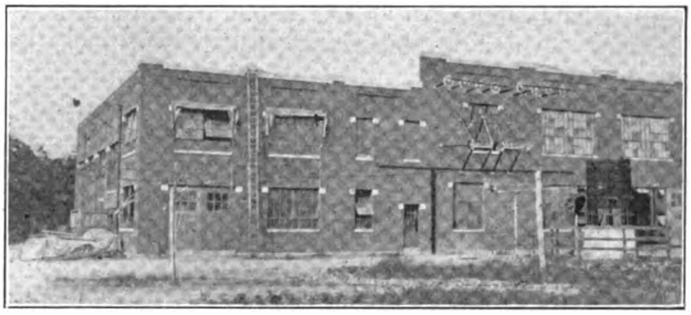

FIG. 18—RADIO TRANSMITTING STATION AT MARION, MASS

problem has been very elegantly solved. The magnetic amplifiers at Port Jefferson are shown in Fig. 17. These ferromagnetic devices accurately modulate or control the flow of power from the alternators to the radiating system or aerial wires. The antenna or aerial wire currents then pass out from the station building through wires supported on special radio frequency insulators. The arrangements employed are given in Fig. 13, which also shows that the modern radio transmitting station (as at Marion) looks much more like a conventional moderate-size power plant than the radio stations of ten years ago, which rather resembled a small physical laboratory.

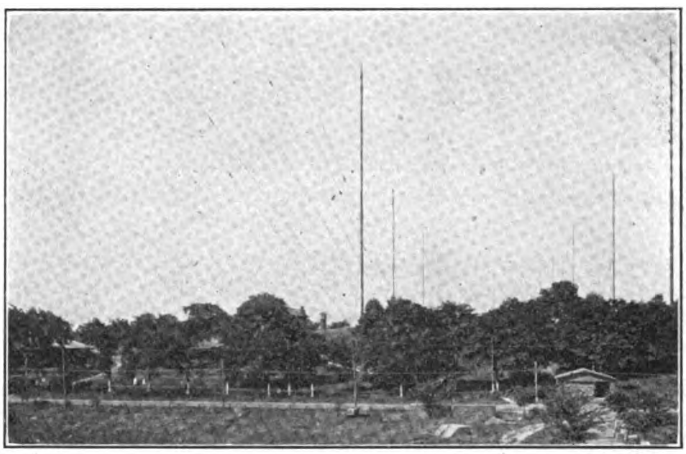

FIG. 19—RADIO ANTENNA STRUCTURE AT NEW BRUNSWICK N. J.

To radiate the large amounts of power required to bridge transoceanic stretches, a large and lofty radiating system or antenna is required. The main tower at Tuckerton is 850 feet (250 meters) high. A type of antenna system is pictured in Fig. 19, this being the structure at New Brunswick. A row of 400-foot masts stretching 6000 feet from the station support the "multiple tuned" antenna system. The latest

form of antenna support is shown in Fig. 20. It consists of a line of 400-foot towers with 150-foot spreaders at the top of each, and stretching a mile and a half from the station. Twelve such rows of towers, each fed by its own alternators and constituting in effect a separate transmitting station, are to be erected at the New York Radio Central located near Port Jefferson, Long Island. An area of about ten square miles is being devoted to this giant station, which will be by far the largest in the world when completed.

In radio reception there have also been very marked advances during the last few years. Each row of apparatus in its specially shielded cases is capable of handling one transoceanic channel. Each operator is provided with a telegraph key controlling the transmitter on the corresponding circuit, so that he can, if necessary, "break" or interrupt the transmitting operator to obtain a correction or other information

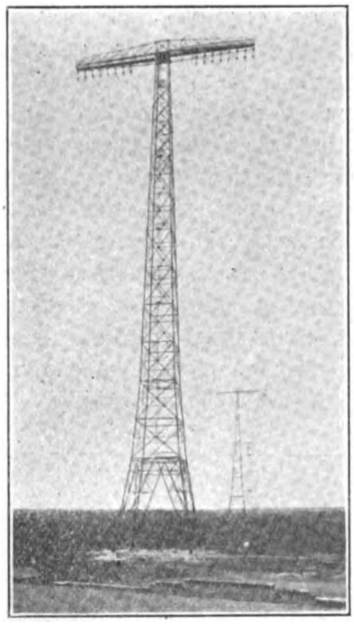

FIG. 20—ANTENNA TOWERS AT RADIO CENTRAL, LONG ISLAND, N Y

from the station which he is receiving. When reception at high speed was desired, recording was sometimes accomplished on modified phonographs which were run rapidly and the records were later transcribed at lower speeds by a number of operators. This method of receiving at high speed has been superseded by modern forms of ink recorders specially developed for radio reception. Such an ink recorder is shown in Fig. 21, and the details of its construction and use will be described in papers shortly to be presented before an engineering Institute. The Broad Street, New York, operating room with some of its recorders installed is illustrated in Fig. 22.

At the New York Radio Central on Long Island, the seventy-two towers previously mentioned cover an area which stretches nearly halfway across Long Island. It is perhaps unfortunate that the eye of man is not capable of perceiving the long wave light which will be radiated from this station, or, as it is more commonly called, the radio wave. If this light were but visible, the pulsations of the dots and dashes sent from the twelve radiating aerial systems would appear to the distant observer as brilliant flashes emanating from a tremendous blazing hemisphere surrounding the station area.

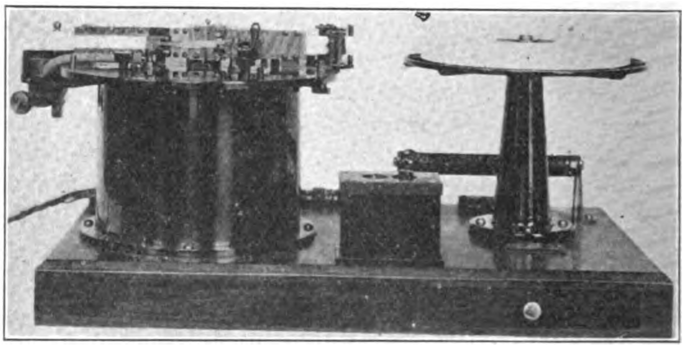

FIG. 21—INK RECORDER USED TO RECEIVE RADIO SIGNALS

As has been mentioned, wire and radio communication should work hand in hand in any comprehensive scheme of world communication. The land lines and cables have very clearly demonstrated their great capabilities and usefulness, but radio communication, even at this early state in its development, has shown that it should be considered as an integral element of any well-considered plan for communicating all over the globe. Today approximately 15 per cent of the traffic across the Atlantic from the United States is handled via radio, which is a hopeful showing for a

FIG. 22—NEW YORK CITY OFFICE OF RADIO CORPORATION OF AMERICA

new art. To the extent that there is harmonious and intelligent cooperation between the various communication systems, we may hope for the satisfactory solution of the problem of giving every person on earth rapid and reliable communication. Fortunately there are no physical limitations to prevent the interconnection by skilled persons of wire line and radio circuits.

Messages received by radio telegraphy or radio telephony can be automatically transferred to wire lines and over them relayed to any point reached by them. Conversely, telegraph or telephone signals on a wire line can be used to control radio telegraph or radio telephone transmitters. So that any wire system may be extended by the addition of radio relays and, reciprocally, any radio system may be extended by the addition of wire relays. This process of adding wire and radio links or relays to each other can be carried on to practically any desired extent and should constitute an element in the communication systems of the future under the circumstances previously mentioned. On a moderate scale it is being carried out commercially today in the case of messages from Europe received by the Radio Corporation of America at its receiving stations on Long Island and in New Jersey. From these points the messages are automatically relayed over wire lines to the New York office of the Corporation at Broad Street, where the receiving operators take down the messages by ear, if sent at hand speed, or the messages are automatically written down by ink recorders if received at high speed. A similar transfer of telephone signals to and from wire lines is being demonstrated as a commercial proposition in highly successful fashion by the American Telephone and Telegraph Company in the Avalon-Los Angeles radio toll circuit and in the tests with the steamship *Gloucester* equipped with a radio telephone set, enabling any telephone station in the wire system to be connected with persons on shipboard. It has also been similarly carried out experimentally in Japan through the linking of radio telephone receiving and transmitting stations on the coast with the wire line systems of the country, thereby enabling telephone subscribers to communicate directly in certain cases with persons on shipboard.

Certain countries, such as the United States, are so situated geographically as to serve naturally as important relay centers for intercontinental communications. Communications from Europe to South America, and from Europe to the Far East naturally pass over the United States. In view of the rapid rate at which the power required to bridge a certain distance reliably by radio increases with distance for spans of more than a few thousand miles, it is advantageous to establish relay points in the United States whereby communications from Europe to the regions named will be received in the United States and thence automatically or otherwise relayed to their destinations.

Some doubt may have been entertained by engineers as to the traffic-carrying capacity of the ether for long-distance communication. The figures for long-distance telegraphy can be at least roughly estimated without serious difficulty. We shall assume continuous wave transmission, with an appropriate form of key modulation in sending the dots and dashes, and without any tone modulation whatever. Under these conditions, and taking into account both side bands produced as the result of the actual transmission, it has been found that a speed of 100 words (or 500 letters) per minute corresponds to the occupation of a band of frequencies in the ether roughly 100 cycles wide. This is on the basis that the radio-frequency generator maintains its frequency constant during transmission. We shall also assume that the receiver is sufficiently selective to exclude all signals on frequencies outside of this 100-cycle band. Under these conditions, we may say roughly that on each cycle per second of available ether frequencies we can transmit one word per minute. (It must be noted that there is a correction factor required for reducing theoretical "five letter words" to actual "paid words," but this may be neglected for the purposes of this general discussion.) Assuming further that long-distance traffic will be handled in the range of wave lengths between 6000 meters and 40,000 meters, a reasonable assumption on the basis of present day practise (and also a conservative one), we shall have available a band of ether frequencies of from 50,000 to 7500 cycles per second, or 42,500 cycles in all. Accordingly, we can ultimately transmit at least 42,500 words per minute via radio over long distances, or no less than 61,200,000 words per day. If we extend the range of available wave lengths for long-distance communication below 6000 meters through the further reduction of atmospheric disturbances, if we eliminate one of the side bands resulting from transmission, and if we assume the possibility of using the same wave length for transmission at several points of the earth's surface with directional discrimination between the several transmitters at the receiving station, the already enormous daily message-carrying capacity of the ether will be greatly increased. As a matter of comparison, we may state that the figure of 61,200,000 words per day is roughly 150 times the actual traffic sent across the Atlantic Ocean by cable and radio at the present time. A number of perfectly reasonable requirements must be met by transmitting and receiving stations in order to realize the ultimate capacity mentioned above. The transmitters must have strictly constant generator frequency and must occupy the minimum band of frequencies consistent with their key signaling speed. And the receivers must be highly selective for a correspondingly narrow range of frequencies and yet follow the signals accurately. Even today radio engineers are confident that these results will shortly be obtained by carefully chosen technical expedients.

The nature of world communication makes it international in character. Both wire lines and radio waves know nothing of national boundaries, a fact which is sometimes resented by the nations, particularly during hostilities. It is this essentially international character of long-distance communications, particularly of the unguided variety, which has led to the international regulation of radio communication. In 1912, the

London Radio Convention was agreed to by most of the nations of the world and given force by corresponding national legislation in each case. These regulations of the London Convention were fairly general in character and covered the most essential points only. Thus there was left considerable and proper leeway for each nation to settle its own national problems in communication according to local needs and the nature of local institutions. It would seem that some such policy is wise. That is, where important matters of truly international scope clearly require settlement in the interests of effective communication and to avoid inevitable disputes, international regulation has value in the radio field. Beyond this point, which is defined without much difficulty by the experts in the art, regulation becomes burdensome and tends to retard the progress of the radio art and to discourage initiative. At the present time, an International Radio Conference is being arranged for early in 1922 at which a new and up-to-date set of international regulations will be proposed for adoption. The increasing vogue of radio communication and the capabilities of the more modern apparatus make the task of the International Conference a difficult one. For it is a fact that one technically objectionable transmitter not only lowers the grade of its own service but seriously interferes with many other high-grade transmitters and receivers. The paramount necessity for the maintenance of a reasonably high standard for all transmitters and receivers in the radio art is not paralleled to the same extent in any other field of communication. Indeed this is only one of the many respects in which the practise, both in engineering methods and in traffic handling, differs for unguided communications from that for guided communications. The United States has wisely never adhered to any international convention covering wire or cable communications. On the other hand, its policy has been sympathetic toward international radio regulation within the properly restricted limits previously mentioned.

For the rapid growth of world communication, as far as radio is concerned, the degree of regulation of the art by the various governments should be restricted to the enforcement of the international regulations together with such control of the nationality of the owners and personnel of the radio companies as may be deemed necessary for national security. The entire field of unguided communication is so new and is developing so rapidly that great harm can be done by well-meaning but injudicious legislators and officials. Like all pioneer arts, its successful and speedy development depends on wide freedom of experiment by enterprising investigators and encouragement of effort on the part of wide-awake companies.

There is a type of possible world communication which we have not yet considered in detail but which may well have great significance not only for the individual but also for groups of individuals and governments. This is the broadcasting of telegraph messages or of speech. For broadcasting, there is required a powerful transmitting station located as centrally as possible for the area which it is to serve but with due regard to the most desirable point of origin of the broadcast information. With wire or radio relays to the radio broadcasting station, the former point may be largely neglected. For reception of the broadcast messages, there is required a simple selective and sensitive receiver. For such broadcast services as the furnishing of music or speeches, a loud-speaking telephone receiver is a desirable element of the receiving set. For such broadcast service as the supplying of storm warnings, market reports, and the like, the addition of a loud speaking telephone to the receiving set is not so important.

It has been clearly apparent that rural life has been made vastly more pleasant through the farmer's telephone party line, the various forms of small, inexpensive automobiles, gasoline and electric motors, the motion picture, and the phonograph. The addition of high-grade broadcasting of information, both political and agricultural, and of music or other diversions, would be a further very real boon to those living in the less densely populated regions of the earth. There would no longer be the present discouraging isolation and stagnation which is found in so many peasant communities. Clearly we have here a valuable human asset in potential form. As an adjunct to the government, the church, the press, the theater, and other institutions dealing largely with the public, broadcast radio services should have a remarkable future. We can imagine a time when those living in the most remote hamlet may be as completely in touch with world affairs and as free from the boredom which usually accompanies separation from all forms of instruction and amusement as are those living in the crowded metropolis. And perhaps, they may be even better served in that there is likely to be a more intelligent and less indiscriminate choice of the material which is placed at their disposal through the broadcast services.

World communication in its broad realization will have many important effects; among them, commercial, political, scientific, and personal. The effective conduct of international commerce is slavishly dependent on speedy and reliable communication. Unless information and decisions can be rapidly transmitted from one business house to another, or from the headquarters of a business to its subsidiaries and representatives, the pace of business lags greatly and world commerce is discouraged. This fact has been clearly recognized by the greater commercial nations, and is borne out by the vigorous development of the cables by England and of radio communication. by the United States.

There are many ways in which world communication will have political results. In the white light

of unrestricted publicity through the press, it might be anticipated that the policies of the nations must be chosen with greater consideration for the views of their neighbors, with a resulting decrease in friction and irritation between nations. Furthermore, governments provided with effective international communication are able to deal with each other more directly, and without the possible misunderstandings and nerve-racking delays due to repeated handing on of messages from one representative to another. The public tendencies and views of each nation, its aspirations and its methods will all become more clearly known to the remainder of the world, with the result that sources of disagreement can be recognized at an early stage, and the resulting misunderstandings avoided before it is too late. To the extent that definite knowledge by each nation of the faults and virtues of its neighbors can minimize international fallings out, we may confidently expect world communication to promote world peace.

The effectiveness of the life of the individual is greatly dependent on communication. The swift transmission of intelligence in effect extends his personality to any desired point, and enables him to accomplish in a lifetime, without undue effort, what could never have been hoped for in the past. Coincident with the possibility of keeping in touch with friends, family, and business associates at any distance, we find an increased self-confidence and sense of power in the individual and a broader attitude toward the world and its problems. Nor should we fail to appreciate justly the importance of communication within smaller zones. Presumably men will always find their most vital interests within a region of moderate dimensions, and therefore communication within such regions will be of paramount importance. Having satisfied the primary and most important communication needs of each man's city and its suburbs, world communication will extend his reach, when desired, over nationwide and world-wide zones.

Scientific cooperation, both in research and in practise of engineering, has always been slowed up by the lack of communication between the scientists of the various nations. It is curious to note how frequently the same physical law will have the name of a different discoverer attached to it in each country. And since in general, the discoveries were made not long after each other, they were obviously the result of parallel and needless duplication. The establishment of real clearing houses for scientific information and of vigorous cooperation between the widely scattered scientists of the world waits on world communication for its full attainment.

We have reached the day when the cable carries a message from London to New York and gives the answer in three minutes, when a man speaking in Virginia may be heard in Hawaii or Paris, when practically universal telephone service is available throughout the United States, and when the radio messages from Berlin or Honolulu can be written at high speed in ink in New York. If the governments of the world adopt a highly sympathetic and thoroughly warranted attitude toward world communication, if they foster it by all means in their power and vigorously restrain those who would hamper the growing arts which alone can supply such communication, we may confidently expect that the admirable promise of past achievements will be adequately fulfilled in the universal world communication of the future.

CORROSION OF UNDERGROUND PIPES

In certain sections of the country a very serious condition exists in connection with underground pipe systems, owing to the corrosive action of the soil upon the iron of which the pipe is made. The loss from this cause is so large that the Bureau of Standards has recently undertaken an extensive investigation of the subject with particular reference to the corrosive action of soils on gas and water mains.

In this investigation, the Bureau of Standards has the cooperation of the Bureau of Soils of the Department of Agriculture, the pipe manufacturers, and the public utility companies through the Research Subcommittee of the American Committee on Electrolysis. Forty locations have been selected representing the different kinds of soils to be found throughout the United States and at each locality a number of samples of every kind of iron and steel pipe in commercial use will be buried. Some of these samples will be uncovered from time to time to determine the rate of corrosion. Complete data on the physical and chemical properties of the soil and the pipes will be obtained and extensive laboratory experiments will be conducted to determine the effects of variations and individual characteristics of both soils and pipe materials. Some tests of representative pipe coatings will also be undertaken.

The results of the tests should be of great value in determining the importance of soil corrosion and in selecting the kind of pipe best suited for use in any particular soil. It is expected that considerable data as to the relative rates of corrosion of the different kinds of pipe in the soils under observation will be obtained within 2 or 3 years but the investigation will probably continue over a period of 8 or 10 years. Progress reports will be published from time to time as developments warrant.

A Vacuum-Tube Alternating-Current Potentiometer

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A description is given of an alternating-current potentiometer which is suitable for the measurement of electromotive forces having frequencies up to 10,000 cycles per second. Both the phase and magnitude are read directly from the dial settings.

A special type of a-c. differential galvanometer used in connection with the potentiometer is also described.

IN the investigation of many telephonic and acoustic problems it is necessary to measure very small voltages throughout a wide range of frequencies. Because of the outstanding advantages of the potentiometer method for measuring small electromotive forces it has seemed desirable to improve the means of applying it to this service. Numerous difficulties are encountered, however, in attempting to make use of the common types of alternating-current potentiometer circuits. The electromotive forces set up by stray magnetic fields from air-core inductance coils and the stray currents, which pass through the distributed capacities of the coils or through the capacities to ground of the different parts of the circuit, are sufficient to preclude the use of certain forms of apparatus. The Drysdale potentiometer, although relatively free from these sources of inaccuracies, does not cover the desired frequency range and has the further disadvantage of requiring a considerably greater a-c. input than the usual vacuum tube oscillator will deliver without a special amplifier. The form of a-c. potentiometer, which is here described, has been used successfully throughout the frequency range from 60 to 14,000 cycles per second, and the a-c. power required is so small that a standard type of vacuum-tube oscillator may be used as a source of alternating current.

A further advantage of the potentiometer over most of the other types that have been described is the fact that the readings give the phase and voltage of the measured e. m. f. directly. Since most a-c. potentiometer measurements are used in finding the ratio of electromotive forces, it is more convenient to have the readings given in this form than as the sum of two right angle component voltages.

The success of this type of potentiometer depends on the use of vacuum tubes not merely as amplifiers but as unilateral elements to prevent the undesirable reaction of some parts of the circuit upon others. It is thus possible to control the amplitude and phase of comparatively large currents without any troublesome reaction of the load on the controlling circuit. Special precautions have been taken to reduce the effects of stray magnetic fields and of mutual capacities to a minimum. For the sake of convenience in using this apparatus it has been found desirable to construct a new form of a-c. differential galvanometer and a special phase-shifting rheostat. With the potentiometer as constructed measurements of both voltage and phase may be made by a few simple adjustments, and experience has shown that the results are accurate over a wide range of frequencies.

The Circuit

The complete circuit of the potentiometer is shown in Fig. 1. V_1, V_2 and V_3 are three-element thermionic vacuum tubes of the audion type. The secondary of a transformer is connected to a condenser C, and a resistance, R_c, in series. The input terminals of the vacuum tube, V_1 are connected across the condenser, and those of V_2 across the resistance. The output circuits of these tubes operate into the two transformers T_2 and T_3, the secondary windings of which are connected to two equal resistances, R_1 and R_2, respectively. By means of the sliding contacts, k_1 and k_2, part of the resistance R_1, and part of the resistance, R_2 are shunted across the input of the third vacuum tube. The output of this tube operates into a transformer, the secondary of which is connected to the potentiometer slide wire, R. T is either a telephone receiver or a vibration galvanometer, which serves the purpose of indicating when the drop of potential between d and k is the same in magnitude and phase as the unknown electromotive force V_x.

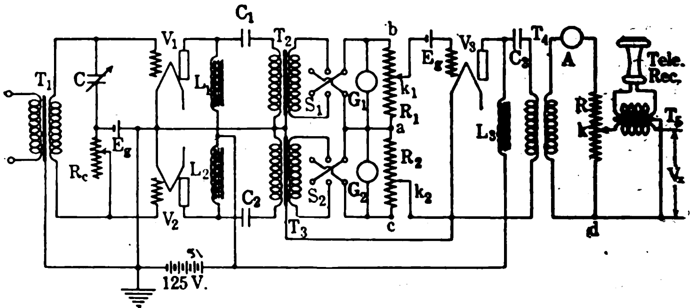

FIG. 1—COMPLETE POTENTIOMETER CIRCUIT

Theory of Operation

If the impedances, R_c and $\dfrac{1}{\omega C}$ are much smaller than the input impedances of the vacuum tubes, the differences of potential across the resistance, R_c, and across the condenser, C, will be practically 90 deg. out of phase. If R_1 and R_2 are equal, the transformers, T_2 and T_3, of identical design, and if the tubes V_1 and V_2, have the same output impedances, the currents in R_1 and R_2 also will be 90 deg. out of phase. By proper adjustment of C and R_c these currents may be

made equal to each other in magnitude. To facilitate this adjustment, one coil of a differential a-c. galvanometer of special design is connected in shunt with R_1, and the other coil in shunt with R_2. By means of the sliding contact, k_1, any fractional part of the voltage drop along R_1, and by means of the sliding contact, k_2, any fractional part of the voltage drop along R_2, may be impressed on the tube, V_3. The two sliding contacts should be rigidly attached to the same dial so that their positions are varied simultaneously. These contacts are placed so that in one extreme position, the input terminals of the tube are connected across R_1 and in the other extreme position across R_2. The phase of the current in R may be varied through 90 deg. by changing the positions of these contacts between the extreme points. By the additional use of the reversing switches the phase may be shifted through 360 deg.

The resistances R_1 and R_2, must be proportioned so that the voltage impressed on the last tube is the same for all positions of the contacts. If $\frac{X}{l}$ is the fractional part of the distance k_1 is moved from a to b, and $\frac{1-x}{l}$ the fractional part of the distance k_2 is moved from c to a, then the resistance between a and k_1 should be

$$R \cos \frac{x}{l} \frac{\pi}{2},$$

and that between k_2 and a,

$$R \sin \frac{x}{l} \frac{\pi}{2}$$

The voltage between k_1 and k_2 will then be

$$I R \cos \frac{x}{l} \frac{\pi}{2} \sin p t + I R \sin \frac{x}{l} \frac{\pi}{2} \cos p t$$

$$= I R \sin \left(p t + \frac{x}{l} \frac{\pi}{2}\right)$$

where $I \sin p t$ and $I \cos p t$ are the currents in R_1 and R_2, respectively. Hence, in this case the magnitude of the voltage between k_1 and k_2 is constant and the scale of phase is linear. This arrangement then provides a convenient way of varying the phase of the output current of the last tube without varying its magnitude.

In making a measurement of the voltage, V_s, the phase of the current in R and the position of the contact, k, are adjusted so that no tone is emitted by the telephone receiver, T. If then I is the current flowing through the resistance, R, the magnitude of this voltage is equal to $r I$, where r is the resistance between the points d and k.

The Phase-Shifting Rheostat

With the slide wires, R_1 and R_2, arranged as shown in Fig. 1, it would be necessary to have 900 points of contact if adjustments for phase were to be made to 1/10 of a degree, as is often necessary for obtaining complete silence in the telephone receiver, T_1. By

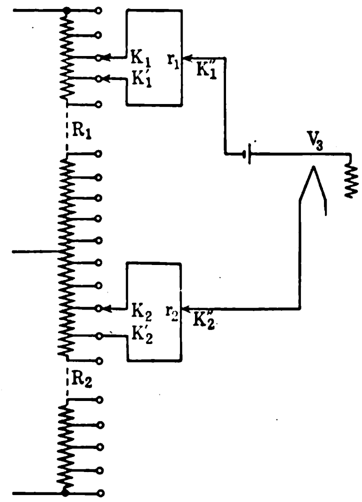

Fig. 2—Double Set of Contacts

the use of a double set of contacts as shown in Fig. 2, the construction is simplified. The sliding connectors, k_1 and k_1', make contact with two adjacent posts. These sliding connectors lead to the terminals of a secondary slide wire resistance, r_1, which should be large compared with that part of R_1 coming between any two adjacent contact posts. The sliding contacts, k_1, k_2, k_1' and k_2' are connected mechanically so that all four are moved simultaneously, likewise k_1'' and k_2''. The dial controlling the former set of contacts then serves for coarse adjustment of phase and that regulating the position of the latter for fine adjustment. In practise it has been found convenient to have 46 contact points on each of R_1 and R_2 so that one step on the first dial shifts the phase through two degrees. With the second dial the phase adjustment may then be made to within a fraction of a degree.

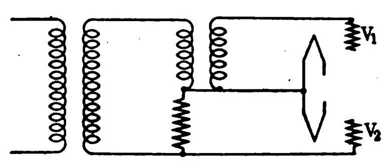

Fig. 3—Diagram of Diferential Galvanometer

The A-C. Differential Galvanometer

In Fig. 1 is shown how the two coils of a differential galvanometer are connected in the circuit to indicate when the potential differences across R_1 and R_2 are equal in magnitude. Most of the different types of instruments described in the literature which might be used for this purpose depend for their action on a heating element. However, hot wire instruments have

to be readjusted frequently, burn out with a very small overload and have a comparatively low sensitivity. In general, they also have a low resistance and so are adapted to comparing currents rather than voltages. An electrodynamic type of differential galvanometer was therefore designed, which gave entirely satisfactory results.

Fig. 3 will make clear the construction of the instrument. To the frame, B, are attached two small shell-type transformers, of which D_1 and D_2 are the primary windings. The secondary windings, consisting of the aluminum rings, S_1 and S_2, *i. e.*, of single short-circuits turns, are rigidly held together by the bar, A, and thus form with the mirror, M, the moving system suspended at P.

When an alternating potential difference is applied to one of the primary coils a force of repulsion will be set up between this coil and the corresponding secondary winding. If then the two transformers are exactly alike and the point of support, P, is midway between the coils, S_1 and S_2, there will be no rotation of the moving system from its normal position whenever the electromotive forces impressed on the primary windings are of the same frequency and are equal in magnitude. The instrument thus affords a convenient method for determining the equality of two voltages of the same frequency.

Neither the impedance nor the sensitivity of this instrument is constant with frequency. But this defect is of no great consequence so long as the use of the instrument is confined to a comparison of voltages of the same frequency. This case, in fact, is the only one where this particular type of differential galvanometer has any practical value. Here, however, it has the following points to commend it. The primary coils may be wound to any desired impedance so that the galvanometer can be adapted for use in circuits carrying either large or small currents. The sensitivity appears to be several times greater than that of the various hot-wire types of instruments. The instrument may be subjected to a very large overload without injury. The moving system has exceptionally good mechanical characteristics, short period and high damping. An advantage of this type of instrument over one that might be constructed on the principle of the ordinary electrodynamometer, is the fact that no lead wires are required for sending current through the coils of the moving system. The mechanical construction is therefore much simpler in this respect.

Sources of Inaccuracies

Since one of the output terminals of a vacuum-tube oscillator is generally either completely grounded, or has a comparatively low impedance to ground, the mutual capacity between the primary and secondary windings of the transformer, T_1, should be small, otherwise the condenser, C, and the resistance, R_c, will not be traversed by the same current. In this case the potential difference across the condenser and the resistance will not necessarily be 90 deg. out of phase. Inaccuracies on this account may be kept small if the transformer has a grounded shield between its windings and if the capacity between this shield and the secondary winding is small compared with the capacity of the condenser, C. In order to have the phase difference of the voltages impressed on the tubes, V_1 and V_2, accurately 90 deg. out of phase the input impedance of these tubes should be large. On this account it is best to use tubes with a low amplification constant.

At low frequencies the impedances of the stopping condensers, C_1 and C_2, may be comparable with the input impedances of the transformers, T_2 and T_3. These condensers should therefore have very nearly equal capacities. For the same reason the impedances of the coils, L_1 and L_2, should be large and have very nearly the same values.

As may be seen from Fig. 1, the resistance, R_2, is grounded at one point whereas R_1 is not. If the mutual capacity between the primary and secondary windings of the transformers, T_2 and T_3, is appreciable, then because of this dissymmetry, the current in R_1 will not be accurately 90 deg. out of phase with the current in R_2, even if the voltages impressed on the primaries of the transformers are 90 deg. out of phase. It is therefore preferable to place a grounded shield between the windings of these transformers. Inaccuracies on account of dissymmetry will not be eliminated altogether by this arrangement, but will be small, if the capacity between the shield and the secondary winding of the transformers is small and balanced.

The resistance, R_1 and R_2, should not be so large that the current through these resistances will be changed appreciably when shunted by the input impedance of the tube, V_3; for this reason this tube should also have a small amplification constant.

The telephone receiver, T, when in use, is necessarily partially grounded; hence, if there is any mutual capacity between the windings of the transformer, T_5, current will flow from the primary winding through the secondary to ground and a false balance will be obtained. It is advantageous, therefore, to use here a transformer with a grounded shield between the windings. If the capacity of the primary winding to this shield is balanced, the current through the receiver, T, will in all cases be equal to zero whenever the drop of potential between K_3 and d is equal to V_x.

A Modification of the Circuit

Instead of a condenser, C, (Fig. 1) a mutual inductance may be used in the manner shown in Fig. 4. It is evident that, theoretically at least, the voltages impressed on the tubes, V_1 and V_2, will be 90 deg. out of phase as in the preceding arrangement. However, this circuit is less desirable because the electromotive

forces impressed on the two tubes, will in practise not be 90 deg. out of phase on account of the distributed capacity in the inductance coils, which cannot be avoided entirely. A further disadvantage on the use of inductance coils in place of a condenser is that stray magnetic fields may induce electromotive forces in other parts of the circuit and thus cause serious errors.

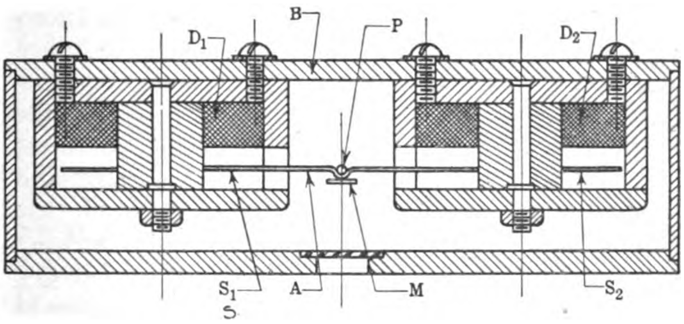

FIG. 4—MUTUAL INDUCTANCE USED IN PLACE OF CONDENSER

MECHANICAL CONSTRUCTION

Fig. 5 shows the general appearance of a form of potentiometer which was constructed on the principle just described. All the electrical parts of the apparatus are placed within a shielded box, to the vulcanite cover of which are attached the control dials and switches. For the various functions of these refer to Fig. 1. Dials 1, control the capacity of the condenser

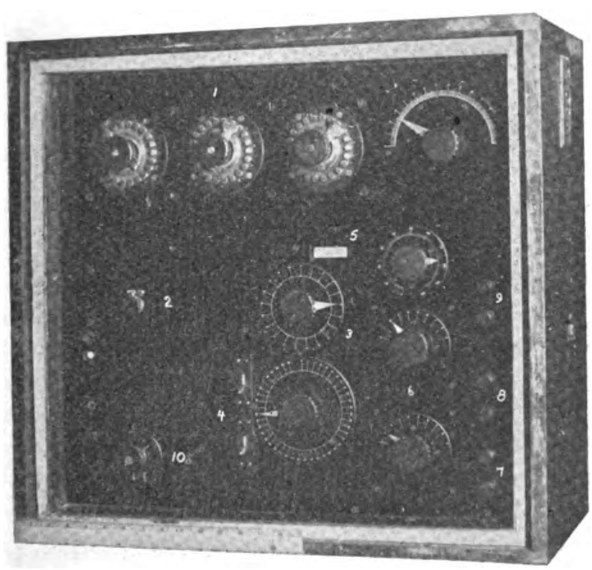

FIG. 5—POTENTIOMETER

C; the maximum value of the capacity of this condenser is 1 microfarad. By means of the switch, 2, R may be given a value of either 1000 or 6000 ohms, the latter being used for frequencies below 200 cyles per second. Coarse and fine adjustments of the phase-shifting rheostat are made by the dials, 3. The reversing switches, 4, correspond to S_1 and S_2 of Fig. 1.

The ground glass window, 5, on which the light reflected from the mirror of the differential galvanometer is brought to a focus, serves to indicate when the voltages across the two coils of the galvanometer are equal in magnitude. A resistance dial, 10, controls the filament currents of the vacuum tubes. Dials, 6, regulate the slide wire resistance and so the potential drop between k_3 and d; the readings of these dials, after a balance has been obtained, thus give the magnitude of the measured e. m. f. To measure the current flowing through the slide wire resistance an a-c. ammeter is connected to the terminals, 7. The measured voltage is brought to the potentiometer through the terminals, 8, and the telephone receiver or vibration galvanometer used in getting a balance is connected at 9.

APPLICATIONS OF THE A-C. POTENTIOMETER

The a-c. potentiometer possesses a number of distinctive advantages over other types of instruments for measuring alternating electromotive forces. One of the most important of these is the fact that its scale is linear, while the deflection of most a-c. measuring instruments, which depend for their action on a heating element or on electrodynamic forces, is proportional to the square of the electromotive force. Thus, since the sensitivity is the same over its whole scale, the potentiometer is particularly well adopted for measuring small electromotive forces on open circuit and in addition it can readily be constructed so as to give precise readings over a wide range of voltages. Electromotive forces ranging from 0.001 to 5 volts may be measured accurately with the potentiometer here described.

The a-c. potentiometer gives the voltage corresponding to the fundamental component only, regardless of the wave form of the electromotive force to be measured. This fact is a distinct advantage in certain classes of measurements, especially where values are to be obtained as a function of the frequency, as in many telephone problems, for, whatever the wave form of the e. m. f. may be, effects due to the higher harmonics are eliminated.

In many alternating-current problems it is of fundamental importance to be able to measure phase. For example, in the study of distortion produced by amplifiers or other circuits in the transmission of currents of complex wave form, it is often necessary to determine the phase relations as well as the comparative magnitudes of the output and input currents at various frequencies. With the a-c. potentiometer here described both quantities are read directly after three simple adjustments.

The instrument is particularly well adapted for determining electromotive forces as a function of frequency, for, the differential galvanometer permits adjustment to be made quickly in going from one frequency to another. Measurements have been made with this instrument and satisfactory results obtained

for frequencies varying from 50 to 14,000 cycles per second.

The compensating potential difference is supplied by means of a slide wire resistance. This arrangement reduces errors on account of capacity to ground to a minimum. Only iron-core transformers and inductances placed within iron cases, are used in the construction of this potentiometer. Stray fields are thus eliminated, which in measurements at acoustic frequencies might have considerable effect on the precision of the apparatus. All the other parts may be enclosed completely in a shielded box. The apparatus is thus entirely protected from outside electrical disturbances.

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NOTES FROM THE BUREAU OF STANDARDS

PARIS CONFERENCE ON RADIO REGULATION

During the past summer, delegates representing the leading nations met in Paris to consider certain technical questions concerned with radio communication and to make a report to the next International Communications Conference.

Radio communication is now regulated in accordance with the London Convention of 1912, and the revolutionary developments in radio since that time have made new regulations imperative.

The Inter-Allied Technical Committee, which sat from June 21 to August 22, considered primarily a set of 14 questions prepared by the Preliminary Communications Conference of the five principal powers which met in Washington in 1920. Two delegates of the Department of Commerce were present. One of the fundamental questions was the classification of waves. The final conclusion really adopts two wave classifications, one by types and one by classes.

The Paris conference did not attempt to allocate particular ranges of long waves to particular countries but formulated the technical principles on which such an allocation should be considered by the next International Communications Conference. The technical principles adopted were in brief: (a) the lower frequency waves should be used for the longer distances and the higher frequency waves for the shorter distances; (b) stations situated in the same general locality and working at similar distances should in principle use adjacent frequencies; (c) each nation should use only the smallest possible number of wave lengths necessary to carry on its radio communication, and (d) use should be made of the directional properties of radio whereby the number of communications carried on in a given region may be increased by employing the same frequency a plurality of times. (This last principle was stated in an appendix to the main conclusions on question 10, but is one of the technical principles laid down.)

The conclusions adopted at the Paris Conference are not binding on any of the governments; they are recommendations made by the conference to each of the five governments represented. It is assumed that they will be the basis of discussion and action at the next World Communication Conference.

A brief typewritten summary of the results of the Paris Conference has been prepared, and interested persons may secure a copy by addressing the Bureau.

CONFERENCE WITH AMERICAN ELECTROPLATER'S SOCIETY

Arrangements have been made for a conference in Washington in the near future with an advisory committee representing the American Electroplater's Society. It is planned to hold such conferences about twice a year in order to afford an opportunity for suggestions or criticisms regarding the work and plans of the Bureau upon electrodeposition and the application of the results in commercial practise.

It is interesting to note in this connection that during the month requests for information or assistance upon electrodeposition were received from five different branches of the government service, namely, the Bureau of Engraving and Printing, the the Hydrographic Office, the Coast and Geodetic Survey, the Quartermaster Corps of the War Department, and the Government Printing Office. In each case some assistance was rendered and arrangements made for further cooperation.

Simple Equations for the Lamp Performance

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New York Edison Company

The paper is concerned with the finding of new empirical equations for the relations between the "fundamental quantities" of incandescent lamps (voltage, efficiency, candle power, life, wattage, current, and resistance). These equations should be simple and should be free from the main drawback of the equations used heretofore, namely, that the reduction from one given value of a certain "fundamental quantity" other than efficiency, to another value, had to be made in two steps, to and from the "normal" value, the normal value being the value corresponding to a certain assumed "normal" efficiency of the lamp. For instance if we wanted to know at what efficiency a lamp will burn under 110 volts if it shows 1.25 watts per c. under 100 volts, we had to find out first at what voltage the lamp is consuming 1.00 watts per c. A number of new equations is given for the voltage-efficiency and the voltage-candle power relations some of them so simple that they do not require evolution. The accuracy is mostly far better than one half of one per cent. The specific difficulties of the problem and the way of overcoming them are pointed out for application to other relations and other lamps than those for which the equations are given in the earlier portion of the paper.

I. Scope and Object of the Investigation

The term "lamp performance" is understood here to mean the way in which the following "fundamental quantities" for incandescent lamps are interrelated: voltage v, candle power c, total watts w, watts per candle (generally, but wrongly called "efficiency") e, ohms r and amperes i.

Volts v, candle power c, and watts per candle e are of prime importance in practise. The relations between efficiency-voltage and voltage-c.p. will be the only ones to be investigated here and the investigation is extended to tungsten vacuum lamps only, but the method devised and explained can be also applied to the other relations (including life l) and to other types of lamps. The object of this article is to establish simple equations for these relations. The questions to be solved are characterized by the following example: A certain lamp, if connected to the voltage v_1, is burning at the efficiency e_1 giving the light intensity c_1 candles; compute the voltage v_2 which will make that lamp burn at efficiency e_2 and the voltage v_2' which will make it emit c_2 candles.

Earlier attempts[1] to find an equation for the lamp performance resulted in exponential equations

$$\frac{e_1}{e_2} = \left(\frac{v_2}{v_1}\right)^g \quad \text{and} \quad \frac{c_1}{c_2} = \left(\frac{v_1}{v_2}\right)^k \qquad (1)$$

where g and k are constants. It was understood that these equations were true only for a very limited percentage of variation of the variables from their "normal" values. (The "normal" values are those which correspond to a certain fixed standard value e_0 of "efficiency," now mostly chosen as one watt per c.)

The next step taken was to make the exponents in the equations (1) variable instead of constant and to make them dependent on the value of the efficiency e referring to a certain standard efficiency e_0. This made it necessary to resolve every operation into two steps taking the reduction to normal efficiency (unity efficiency) or to the corresponding values of the other fundamental quantities for the first step and the reduction from the normal to the desired value as the second. If, for instance, v_1 and e_1 are given and the question is: "What voltage is necessary to make the lamp burn at the efficiency e_2?" we will first have to find what is the "normal voltage" of the respective lamp; in other words what is the voltage at which the lamp will burn, at the "normal efficiency" $e_0 = 1$, using the formula $\frac{e_1}{e_0} = \left(\frac{v_0}{v_1}\right)^{g1}$ The value of g_1 will have to be found from an empirical table or a curve as a function of e_1 Table I[2]. We thus find the normal voltage v_0. The second step is to reduce from v_0 to v_2 by means of the equations $\frac{e_2}{e_0} = \left(\frac{v_0}{v_2}\right)^{g2}$.

TABLE I
(MAZDA LAMPS)
Courtesy of National Lamp Works of G. E. Co.
(Abbreviated from the original.)

Per Cent Volts	Per Cent c.p.	e watt per c.	g
87.30	61.57	1.310	1.990
90.06	68.90	1.230	1.977
95.24	84.17	1.100	1.955
100.00	100.00	1.000	1.935
105.66	121.20	0.900	1.913
110.33	140.70	0.830	1.895
115.75	165.73	0.760	1.876
120.20	188.29	0.710	1.862

where g_2 again will have to be taken from a table and will have a different value from g_1.

This method has two drawbacks. In the first place it is no real reduction of the empirical curve to a mathematical formula; we have only reduced the curve to another (derived) empirical curve, the curve g, by means of a mathematical formula. (The advantage of reducing the original curve to the curve g consists in the fact that the use of the latter curve more effectively smoothes out the little irregularities inherent to any curve based on observations and resulting from inevitable errors of observation, etc., and it permits a

1. Merrill: Trans. A. I. E. E., Vol. 29 1910, p. 959.

2. The author is indebted to the National Lamp Works of G. E. Co. for the permission to use its empirical curves and tables of lamp performance. (Table I.)

more correct approximation to average values from all observations.)

The second and more serious objection is that this method renders the calculation rather tedious and lengthy as we always have to find the normal voltage (or normal candle power etc., as the case may be) as shown above, although we are not interested in it.

Other methods like those of Cady[3], of Middlekauf and Skogland[4] also necessitate finding the "normal values" and involve even more complicated arithmetical work in the evaluation although they are free from the first named objection.

The writer has endeavored to find formulas first for the two most important relations (that is between voltage and efficiency and between voltage and candle power) which give an easy, quick and direct solution with sufficient accuracy, without the use of tables or curves and without the necessity of computing the "normal value."

As regards accuracy, the aim has been at the start to keep the errors (of the formula with regard to the original curve) within the limits of ± 0.5 per cent for the range of efficiencies from 0.70 to 1.30 watts per *c* for the following reasons: The accuracy of individual observations on the photometer runs somewhere between 1 per cent and 1.5 per cent and even if readings are taken by two different observers and then averaged, the figures obtained have no greater reliability than somewhere between 0.5 and 1 per cent. In addition to this the slide rule operations may be said to result in additional errors somewhere between 0.1 and 0.5 per cent. In the face of these errors of the curve to be represented by the formula it does not seem necessary to limit the accuracy of the formula any closer than to an error of 0.5 per cent. As regards the range of the efficiency within which the formula should be of the sufficient accuracy of 0.5 per cent, work with tungsten vacuum lamps is, for purposes of practise, always confined to the range of efficiency given above, that is from 0.70 to 1.30 watts per *c*.

It will be shown however that the accuracy of most of the formulas is much greater than required above (± 0.5 per cent) and also that the range within which the formulas hold true is much wider than what has been planned at the start.

II. Results

As some readers may be interested in the results and not in the method devised to get these results, the results are anticipated herewith.

1. *Efficiency-Voltage.* The equation for the relation between voltage and efficiency is

$$\frac{v_2}{v_1} = \left(\frac{e_1 - 0.1700}{e_2 - 0.1700} \right)^{0.428} \tag{2}$$

from which

$$v_2 = v_1 \left(\frac{e_1 - 0.1700}{e_2 - 0.1700} \right)^{0.428} \tag{2A}$$

or, if the voltages and one of the efficiencies e_1 is given and the other efficiency e_2 is required

$$e_2 - 0.17 = (e_1 - 0.17) \left(\frac{v_1}{v_2} \right)^{2.336} \tag{3}$$

from which

$$e_2 = (e_1 - 0.17) \left(\frac{v_1}{v_2} \right)^{.336} + 0.17 \tag{3A}$$

From the fact that, with constants as exponents the voltages in these equations occur only in their mutual ratio, it is evident that it no longer makes any difference whether we introduce the voltages as percentages of the (unknown) "normal" voltage or measured in any other unit, for instance in volts. Fig. 1 shows the errors resulting from the application of this formula. To obtain the values of the errors in Fig. 1 and the following curves, the values of Table I have been

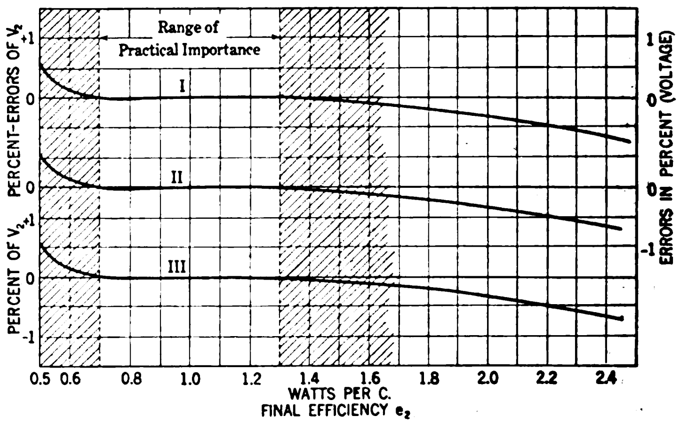

Fig. 1—Error Curves of the Efficiency-Voltage Equation (2)

assumed to be the absolutely correct and accurate ones. The values in this table are the probable values obtained as the averages from a large number of observations on a large number of lamps.

The upper curve of Fig. 1 refers to $e_1 = 0.71$, that is, to reductions from the efficiency $e_1 = 0.71$ to any other efficiency e_2 as given by the abscissa; the second curve refers to $e_1 = 1.00$ that is to reductions from the efficiency 1.00 watt per *c.* to another efficiency e_2, and the third curve refers to $e_1 = 1.31$ watt per *c.* The errors in every one of these three cases remain within much closer limits than has been found necessary above as long as the assumed limits of 0.70 and 1.30 watt per c. (and even much wider ones) are maintained. It may be assumed that with the initial efficiency e_1 anywhere between the values designated by the three curves of Fig. 1 the accuracy will not be essentially smaller than in any one of the three curves.

Example of the Use of this Formula. A lamp is found to be burning at 1.31 watt per c. under 110

3. Cady, *Elec. Review & West. Elec.*, Vol. 59, 1911, page 1092.

4. Middlekauf & Skogland, Transactions Ill. Eng. Soc. 1914, page 744.

volts; how high must the voltage be raised to make the lamp burn at 0.80 watt per c.?

$e_1 = 1.31$ watt per c. $v_1 = 110$ volts

$e_2 = 0.80$ watt per c. $v_2 = ?$

$$\frac{v_2}{v_1} = \left(\frac{e_1 - 0.17}{e_2 - 0.17}\right)^{0.428} = \left(\frac{1.14}{0.63}\right)^{0.428} = 1.2890$$

$$v_2 = 1.2890 \times v_1 = 1.2890 \times 110 \text{ volts} = 141.79 \text{ volts}$$

This however is not the only practical formula for the purpose. The method devised for the derivation of these formulas and described in Chapter III permits, as will be shown there, of developing quite an assortment of formulas. We could get for instance more accurate formulas than the one given, at the price of having a more complicated structure of the formula but as the accuracy of equation (2) is greater than required, these varieties can be left out of considera-

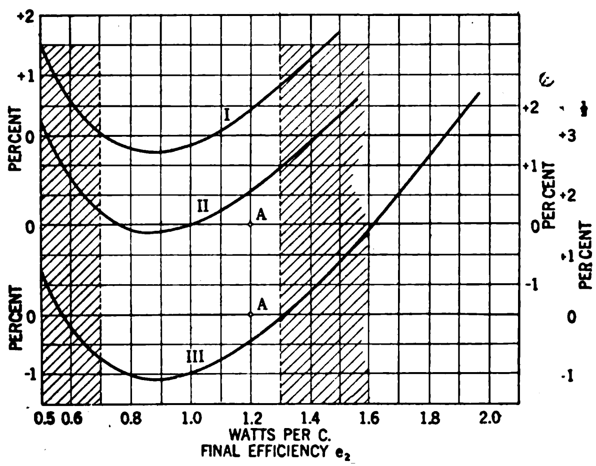

FIG. 2—ERROR CURVES OF THE SIMPLIFIED EQUATION (2B) FOR THE EFFICIENCY-VOLTAGE RELATION

tion. We also can obtain simpler formulas if we are willing to sacrifice a little of the accuracy. Such a relation is

$$\frac{v_2}{v_1} = \frac{e_1}{e_2} \times \frac{e_2 + 1}{e_1 + 1} \qquad \text{(2B)}$$

This equation does not require any involution and no double log slide rule or logarithmic table is necessary for its evaluation. The operations are so simple that they can be quickly made anywhere with nothing but pencil and paper, in some cases even without such help by mental arithmetic alone. The formula contains no constants to be remembered (except unity) and is easy to keep in memory: The ratio of voltages is inversely proportional to the ratio of efficiencies multiplied by a fraction consisting of the direct ratio of the efficiencies with unity added in both the denominator and the numerator.

Fig. 2 shows the error curves for $e_1 = 0.71$, $e_1 = 1.00$ and $e_1 = 1.31$. Error curves for other initial efficiencies can, if required, easily be interpolated by drawing parallel lines to the curves through the respective points of the zero axis, for instance through *A* in curve II or III if the error curve for $e_1 = 1.20$ should be desired. The curves show that the errors are sufficiently small for almost any kind of practical work as they nowhere go substantially beyond one per cent, and only in such cases where efficiencies greater than 1.2 watt per c. are involved do they go substantially beyond 1/2 per cent.

Example: A lamp is burning at an efficiency $e_1 = 1.25$ watt per c. under the voltage $v_1 = 120$ volts; how high must the voltage be raised to burn the lamp at $e_2 = .8$ watt per c.?

$$\frac{v_2}{v_1} = \frac{1.25}{.8} \times \frac{1.8}{2.25}$$

The factors 0.2 and 0.25 cancel out and we get

$$\frac{v_2}{v_1} = \frac{5}{4} \times \frac{9}{9} = \frac{5}{4}$$

from which $v_2 = 5/4 \times 120 = 150$ volts.

With no other known formula would it be possible to solve this problem by mental arithmetic alone. The accurate solution from Table I would be 151.17, or 0.78 per cent greater. This is in accordance with the error curves of Fig. 2.

2. *Voltage-C. P.* The nature of this problem is slightly more complex than the voltage-efficiency problem. The easiest way to understand why this is so, is to examine an example. Let us suppose that we wish to answer the question: If a certain lamp is found to give $C_1 = 100$ candles at $V_1 = 110$ volts, how many candles C_2 will it give at $V_2 = 125$ volts? This problem is indeterminate. The lamp may be a very large one and emit the 100 candles at 110 volts with a more or less red glow, or, on the other extreme, it may be a small lamp burning at great brilliancy under 110 volts. It can be expected that the change of voltage from 110 to 125 volts may effect the candle power differently in the two lamps. Even without going to such extremes, it can be definitely proved from Table I that the problem is indeterminate. To show this, let us first assume that the lamp of the example emits its 100 candles under $v_1 = 110$ volts at an efficiency of 0.90 watt per c. This efficiency e_1 corresponding to c_1 and v_1 will be called "initial efficiency" in the following:

By using Table I we find that the voltage corresponding to 0.90 watt per c. is 105.66 per cent of the normal, and the normal voltage is therefore

$\frac{110}{1.0566} = 104.107$ volts. The light intensity at 0.90 watt per c. is, according to the same source, 121.20 per cent of the normal intensity, so that the "normal" intensity of the lamp of this example is found at $\frac{100}{1.2120} = 82.508$ candles. Raising the voltage to 125 volts means therefore raising it to

$$\frac{125}{104.107} = 120.07 \text{ per cent of the normal voltage}$$

and this percentage of overvoltage corresponds, according to Table I, (interpolation) to 187.62 per cent of the normal intensity or 187.62 per cent of 82.508 candles that is 154.80 candles. The lamp will therefore emit 154.80 candles at 125 volts.[5]

In the same way we find that if the initial efficiency was for instance 1.31 watt per c. instead of 0.90, the intensity at 125 volts would be 158.12 candles or 2.15 per cent higher than in the first case.

This difference is not very great and can be neglected for rough calculations. If we restrict however the permissible errors in c. p. within the limits ± 0.5 per cent, as has been stipulated above, (or if we go outside of the assumed limits of efficiency 0.70 and 1.30) the problem must always state the initial efficiency and every formula for the voltage-candle power relation must of necessity contain the initial efficiency.

On the other hand it is not necessary that the initial efficiency be known with great accuracy, because, as shown in the example, and as will be seen from the formula itself, the influence of the value of the efficiency is a very limited one. If in a certain case it should not be feasible or too troublesome to measure the actual initial efficiency at which the lamp is burning, we have to be content with estimating it by eye-sight from the brilliancy of the filament or by taking the rated efficiency in case the lamp is burning in its regular socket. The error introduced even by a comparatively large error in estimating the initial efficiency will not be great and at any rate smaller than if we leave the initial efficiency out of the formula altogether.

The formula found for the voltage-candle power relation is the following:

$$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - [0.190 + 0.1\,\epsilon_1]}{0.810 - 0.1\,\epsilon_1} \right)^{2.834} \qquad (4)$$

or conversely from this

$$\frac{v_2}{v_1} = (0.810 - 0.1\,\epsilon_1) \left(\frac{c_2}{c_1} \right)^{0.3529} + (0.19 + 0.1\,\epsilon_1) \qquad (5)$$

where $\epsilon_1 = e_1 - 1$ if e_1 is the initial efficiency: ϵ_1 can therefore assume a positive, negative or the zero value.

To restrict the chance of making mistakes in the application of the formula keep in mind that the values of the terms $(0.19 + 0.1\,\epsilon_1)$ and $(0.81 - 0.1\,\epsilon_1)$ which occur in every equation must always add up to unity.

Table II shows how the equations change if the initial efficiency varies in steps of 0.1 watt per c.

5. The secondary efficiency e_2 would be 0.711 watt per c. and is therefore within the assumed range (0.7 to 1.3 watt per c.).

TABLE II

$e_1 = 0.7$	$\epsilon = -0.3$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.220}{0.780}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.780\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.220$
$e_1 = 0.8$	$\epsilon = -0.2$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.210}{0.790}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.790\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.210$
$e_1 = 0.9$	$\epsilon = -0.1$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.200}{0.800}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.800\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.200$
$e_1 = 1.0$	$\epsilon = 0.0$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.190}{0.810}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.810\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.190$
$e_1 = 1.1$	$\epsilon = +0.1$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.180}{0.820}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.820\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.180$
$e_1 = 1.2$	$\epsilon = +0.2$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.170}{0.830}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.830\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.170$
$e_1 = 1.3$	$\epsilon = +0.3$	$\frac{c_2}{c_1} = \left(\frac{\frac{v_2}{v_1} - 0.160}{0.840}\right)^{2.834}$	$\frac{v_2}{v_1} = 0.840\left(\frac{c_2}{c_1}\right)^{0.3529} + 0.160$

Although the constants in the equations of Table II vary over quite a considerable range the values for c_2/c_1 and v_2/v_1 are affected only comparatively slightly

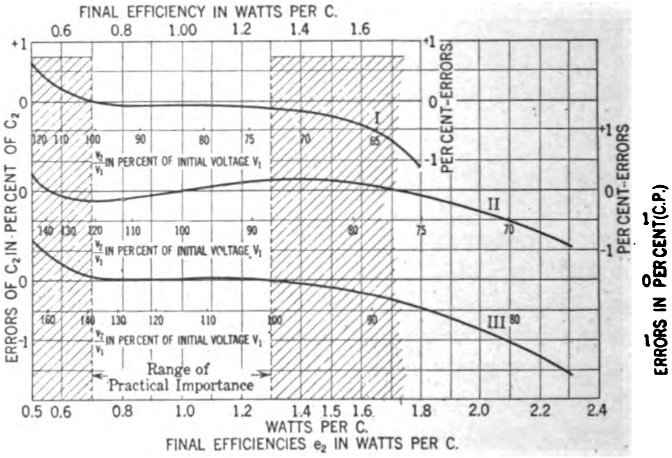

Fig. 3—Error Curves of Equation (4) for the Voltage-C. P. Relation

by these great changes. As we proceed for instance from the top line to the bottom line in the column giving the equations for c_2/c_1 we notice that both the enumerator and the denominator of the fraction are increased by the same amount of 0.01 for every step of the table or by 0.06 between the top and the bottom line. As this amount is not great compared to the

total value of either the numerator or the denominator the effect of the change of the constants on the value of c_2/c_1 is small.

Fig. 3 is the error curve of equation (4) for the three initial efficiencies 0.71, 1.00 and 1.31. Fig. 3 shows

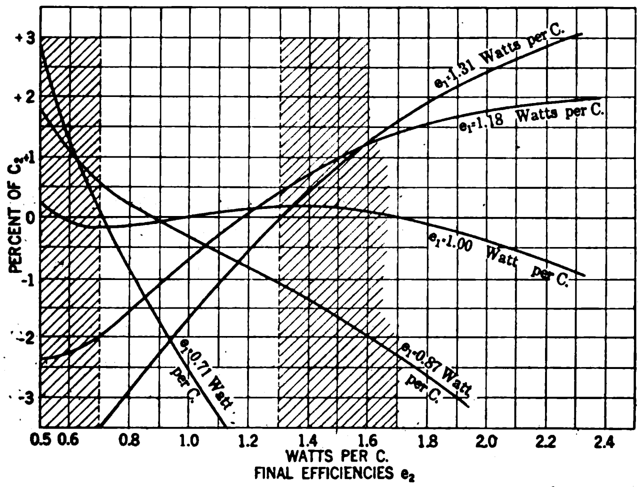

Fig. 4—Error Curves of Equation (4) Neglecting the Correction Factor e_1 to Demonstrate the Influence of this Factor

Compare with Fig. 3

distinctly, as well as Fig. 1, how the error curves, as it were, hug the axis of abscissas in the range for which great accuracy has been aimed at in the construction of the equations, that is in the range of efficiencies between 0.70 and 1.30 watt per c.

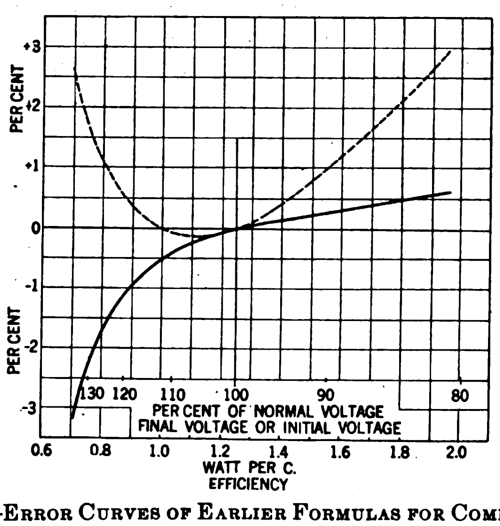

Fig. 5—Error Curves of Earlier Formulas for Comparison

- - - - - $c/c_0 = (v/v_0)^{3.56}$

——— $c/c_0 = (v/v_0)^{3.56}(1 + K)$

where correction factor

$$1 + K = 1 + 0.02\,\frac{v - v_0}{v_0} - 0.5\left(\frac{v - v_0}{v_0}\right)^2$$

Fig. 4 demonstrates the degree of importance of the initial efficiency in a formula for the candle power-voltage relation. In this figure the equation of Table II applying to $e_1 = 1.00$ has been arbitrarily selected and applied to a number of other efficiencies. We get, then, errors as high as 3 and 4 per cent, and even higher, in the range between 0.70 and 1.30 watts per c. The influence of the correction factor in equation (4) (that is, of the members containing ϵ_1) is demonstrated very nicely by Fig. 4, and it can be easily observed how, for instance, the steep error curve for $e_1 = 0.71$ of Fig. 4 is bent by the correction members to follow closely the axis of abscissas in Fig. 3.

Fig. 5 finally shows, for purposes of comparison between the present formula and the older ones, the error curves of the Merrill formula (with constant exponent) and of the Cady formula, both mentioned above. The Middlekauf-Skogland formulas, also referred to above, are extremely accurate, but their use for most practical purposes is out of the question on account of their complicated nature and the numerous operations necessary for their evaluation. The Middlekauf-Skogland equation for the candle power-voltage relation reads

$$\log \frac{v_1}{v_2} = 1.89870 - 1.0282\sqrt{3.41000 - \log c_1/c_0}$$

or conversely:

$$\log \frac{c_1}{c_0} = -9.946\left(\log \frac{v_1}{v_0}\right)^2 + 3.592 \log v_1/v_0$$

and, as stated above, requires reduction in two steps, to and from the "normal" the same as the other older formulas.

III. Derivation of the Equations

The following description of the methods applied for finding the equations may be useful to those who desire to find equations for the relations between the "fundamental quantities"[6] other than the efficiency-voltage and the candle power-voltage relations. It will also be of use if, as the art of lampmaking advances, the two relations just referred to should change and the respective curves alter their shape so that the constants in the equations will also have to be adjusted. The same applies to the establishment of the equations for other types of lamps, for instance the type C Mazda (gasfilled) lamps.

Fig. 6 shows a curve representing in the customary way the empirical relation between the intensity of light emitted as ordinate and the voltage as abscissa. It will be noted that neither the candle power nor the voltage is given in the usual units, but as percentages of certain "normal" values of the voltage and the candle power, respectively; that is, the units are the voltage v_0 at which the lamp has to burn if it shall have a certain "normal" efficiency e_0 (for type B or vacuum tungsten lamps at present generally assumed to be one watt per c.) and the candle power c_0 which the lamp emits if burning at that normal efficiency. The

6. See the introductory words of this paper.

same applies to all the other "fundamental quantities." If therefore v, c, w, i, and r designate the voltage in volts, intensity in candles, energy in watts, current in amperes, and resistance in ohms, respectively, the length of the abscissas and ordinates of the respective curves do not represent v, c, w, etc., but v/c_0, c/c_0, w/w_0 etc. where the index $_0$ designates here, and in the following, the normal value.

1. *Voltage-Efficiency Curve.* The empirical curve between v/v_0 (percentage volts of the normal voltage) as abscissas and the efficiencies as ordinates resembles roughly an equilateral hyperbola corresponding to the equation $v/v_0 \cdot e = K$. In order to make a closer fit between the given curve and the equation the latter has been extended by shifting the asymptotes parallel to themselves away from the axes

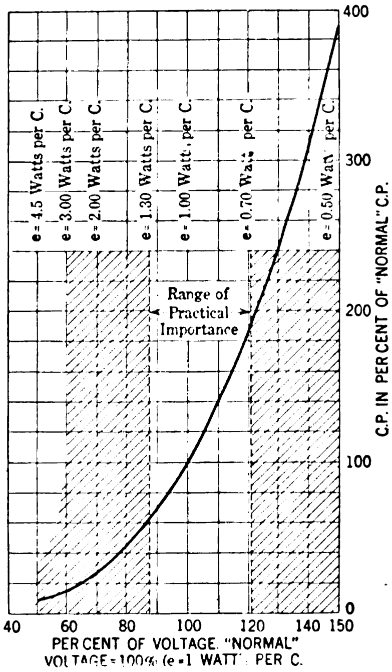

FIG. 6—VOLTAGE-C.P. CURVE

of co-ordinates, and by choosing a hyperbola of the nth order instead of an equilateral one. The equation then becomes

$$(v/v_0 - a)\,(e - b)^n = K \tag{6}$$

This equation contains four unknown constants a, b, n, and K, besides the given normal voltage of the lamp, which is the unit of the voltages in this formula. Obviously the four constants will assume different values if the units chosen for v and e vary.

As explained above we wish to make the equation independent of the unit chosen for the voltage, so that the use of the formula for reducing from v_1 to v_2 does not necessitate computing the "normal" value v_0. This can be done by transforming the equation in such a way that the term for the voltage v does not occur otherwise than in a ratio between two voltages other than v_0.

Applying equation (6) to a given point I (e_I, v_I) permits of expressing v_I/v_0 in terms of e_I and of the constants. The same can be done for another point II of the empirical curve with the co-ordinates (e_{II}, v_{II}). By dividing one of these two equations by the other one v_0 cancels out and we get

$$\frac{v_I}{v_{II}} = \frac{\dfrac{1}{(e_I - b)^n} + \dfrac{a}{K}}{\dfrac{1}{(e_{II} - b)^n} + \dfrac{a}{K}} \tag{7}$$

Voltages occur in this equation only as mutual ratios and the equation holds good therefore for any unit voltage, consequently also for the customary unit of the volt.

This equation contains four constants a, b, n, and K, and the corresponding curve can therefore by proper choice of the numerical values of these constants be made to pass through any desired four points of the empirical curve.

Trials demonstrated at once that the accuracy of this equation is far greater than that at which we are aiming (1/2 per cent) and therefore the formula can be simplified by assuming one of the constants at a convenient value ($a = 0$, $b = 0$, or $n = 1$). The three remaining constants of the simplified equation can then be found in the ordinary manner by applying the equation to three different points and solving for the constants.

Carrying out the first one of these possibilities ($a = 0$), that means letting one of the two asymptotes coincide with the v-axis, and applying the equation to three points at adequate distances within the range for which the equation is to be used, for instance at $e_1 = 1.230$, $e_2 = 1.000$, and $e_3 = 0.730$ watt per c., results, after proper reduction, in

$$\frac{v_2}{v_1} = \left(\frac{e_1 - 0.170}{e_2 - 0.170} \right)^{0.428} \tag{8}$$

identical with (2)

Following the second one of the above named possibilities and letting $n = 1$ we get, after proper reduction,

$$\frac{v_2}{v_1} = \frac{e_2 + 1.812}{e_1 + 1.812} \cdot \frac{e_1 + 0.143}{e_2 + 0.143} \tag{9}$$

This formula which is still too complicated for practical use can be simplified in the following manner. Each one of the two fractions on the right hand side of the equation contains a constant. Increasing this constant has the effect that the value of the respective fraction changes in such a manner that it approaches the unit and vice versa. Whether this means a decrease or an increase in the value of the fraction depends on whether the fraction is greater than or less than 1. Obviously one of the two fractions is greater than the unit and the other one smaller than the unit. Therefore, if we decrease the value of the constant in both fractions, the changes in the values of the fractions

will be of opposite direction and have the tendency to counteract each other in the product of the two fractions. There exists therefore the possibility of simplifying formula (**9**) by reducing the constants over a rather wide range to convenient values, 1 or 0 respectively with a comparatively small reduction in the accuracy. Indeed formula (2B) which has been derived from (**9**) in this manner shows still a good error curve (Fig. 2).

2. *Voltage-C. P. Curve.* The empirical voltage-c. p. curve (Fig. 6) has a shape suggesting a parabola $y = A\, x^m$ where x is the voltage in units of the normal voltage v_0 and y is the candle power in units of the normal candle power.

$$c/c_0 = A\,(v/v_0)^m \qquad \textbf{(10)}$$

Moving again the apex of the parabola away from the origin of coordinates in order to get the possibility of having the parabola pass through a greater number of points of the empirical curve we get

$$\frac{c}{c_0} - b = A\left(\frac{v}{v_0} - a\right)^m$$

or

$$\frac{1}{A}\,\frac{c}{c_0} = \left(\frac{v}{v_0} - a\right)^m + \frac{b}{A} \qquad \textbf{(11)}$$

Here again we wish to get the equation free from the "normal" values c_0 and v_0. We can do this, as far as c_0 is concerned, by the same method as has been applied in the previous section for the elimination of v_0 in the voltage-efficiency relation, but this method is not applicable to the present equation for the elimination of v_0.

It has been shown above that the relation between candle power and voltage cannot be stated with the desired degree of accuracy without introducing the initial efficiency e_1. It is therefore necessary that this efficiency e_1 appears in the formula for the candle power-voltage relation.

In order to free equation (11) from v_0 and at the same time to introduce e_1 we first eliminate c_0 as described above and write the result as follows:

$$\frac{c_2}{c_1} = \frac{\left(\frac{v_1}{v_0}\cdot\frac{v_2}{v_1} - a\right)^m + \frac{b}{A}}{\left(\frac{v_1}{v_0} - a\right)^m + \frac{b}{A}} \qquad \textbf{(11A)}$$

Then we substitute equation (**9**) into (**11a**) writing the former as follows: (remembering that $e_0 = 1$)

$$\frac{v_1}{v_0} = \frac{e_1 + 1.812}{e_0 + 1.812}\cdot\frac{e_0 + 0.143}{e_1 + 0.143}$$

$$= 0.4065\,\frac{e_1 + 1.812}{e_1 + 0.143} \qquad \textbf{(12)}$$

This substitution results in

$$\frac{c_2}{c_1} = \frac{\left(0.4065\,\frac{e_1 + 1.812}{e_1 + 0.143}\cdot\frac{v_2}{v_1} - a\right)^m + \frac{b}{A}}{\left(0.4065\,\frac{e_1 + 1.812}{e_1 + 0.143} - a\right)^m + \frac{b}{A}} \qquad \textbf{(13)}$$

This formula would be unnecessarily accurate and we have again the choice how to simplify it for practical use by selecting certain ones of the constants at convenient values at the expense of the accuracy of the formula.

If we let $b = 0$, that is we shift only the vertical or c/c_0 axis but not the axis of v/v_0 we get after proper reduction:

$$\frac{c_2}{c_1} = \left\{\frac{\frac{v_2}{v_1} - 2.460\,\frac{e_1 + 0.143}{e_1 + 1.812}\,a}{1 - 2.460\,\frac{e_1 + 0.143}{e_1 + 1.812}\,a}\right\}^m \qquad \textbf{(14)}$$

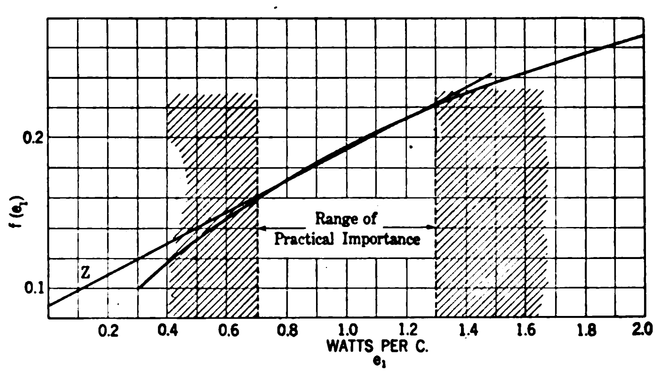

Fig. 7—Approximation of $f\,(e_1)$ by a Straight Line

This formula is now applied in the usual manner to three points of suitable location or in other words to two different sets of c_2/c_1 and the two constants a and m are thus evaluated as 0.1927 and 2.834 respectively. With these values substituted equation (**14**) changes into

$$\frac{c_2}{c_1} = \left[\frac{\frac{v_2}{v_1} - f\,(e_1)}{1 - f\,(e_1)}\right]^{2.834} \qquad \textbf{(15)}$$

where

$$f\,(e_1) = 0.474\,\frac{e_1 + 0.143}{e_1 + 1.812} \qquad \textbf{(16)}$$

This equation requires further simplification in order to be of practical usefulness. If we plot the values of $f\,(e_1)$ against e_1 (Fig. 7) we see in the first place that $f\,(e_1)$ is always small as compared to the members from which it is to be subtracted in equation (**15**). Since moreover $f\,(e_1)$ is to be subtracted from both the enumerator and the denominator of the fraction in equation (**15**) it follows that even comparatively large inaccuracies in the value of $f\,(e_1)$ will

result in but small errors of c_2/c_1. We can therefore replace the curve in Fig. 7 by the straight line $z\,z$ and as the errors introduced into $f(e_1)$ by that simplification are small within the range of practical usefulness ($e_1 = 0.70$ to $e_1 = 1.30$) we will practically not change the accuracy of equation (**15**) by that alteration.

The equation of the straight line $z\,z$, as can be easily seen, is $z = 0.089 + 0.103\,e_1$. Substituting this for $f(e_1)$ in (**15**) leads to

$$\frac{c_2}{c_1} = \left\{ \frac{\frac{v_2}{v_1} - 0.089 - 0.103\,e_1}{0.911 - 0.103\,e_1} \right\}^{2.834} \qquad (\mathbf{17})$$

or setting $e_1 = 1 + \epsilon_1$

$$\frac{c_2}{c_1} = \left\{ \frac{\frac{v_2}{v_1} - 0.192 - 0.103\,\epsilon_1}{0.808 - 0.103\,\epsilon_1} \right\}^{2.834} \qquad (\mathbf{18})$$

Again we can, without essential impairment of the accuracy, introduce round figures for the constants and write

$$\frac{c_2}{c_1} = \left\{ \frac{\frac{v_2}{v_1} - [\,0.190 + 0.1\,\epsilon_1\,]}{0.810 - .1\,\epsilon_1} \right\}^{2.834} \qquad (\mathbf{19})$$

which is the final formula and identical with equation (4) and the equations of Table II. The errors are represented by the error curve Fig. 3.

Application of Electricity in Processes Leading up to Surface and Subsurface Printing

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Introductory

The data presented herewith have been prepared as part of a report on "Electric Power in the Printing Industry." For the purpose of this report the printing industry has been divided into two general classes as follows:

A. Raised surface or typographic printing, including stereotype printing (newspaper), electrotype printing (magazine and book work), and printing directly from the type forms.

B. Surface and subsurface printing.

This paper refers to motor drive and other electrical applications subsidiary to surface and subsurface printing. This class may be divided as follows:

1. Surface or planographic printing, or lithography.
   - (a) Stone lithographic printing (maps, labels, etc.)
   - (b) Rotary litho printing on zinc or aluminum plates (posters, calendars, labels, etc.)
   - (c) Offset printing (fine art reproductions).
2. Subsurface printing.
   - (a) Engraving.
     - (1) Cards and letterheads (die press work)
     - (2) Steelplate engraving (paper money, bonds, stock certificates, postage stamps, etc.)
   - (b) Rotogravure process (illustrated sections of Sunday newspapers).

Lithography

Commercial lithography today is of three general classes: (1) Work done on flatbed presses, where the impression is taken directly from the lithographic stone, whose surface has been prepared and on which the designs have been impressed; (2) work done on rotary presses where the impression is taken directly from a curved plate of zinc or aluminum on whose surface the designs have been impressed in a manner similar to the designs on stone; (3) work done on rotary offset presses, where the impression is taken from a curved metal plate to a rubber blanket secured to an adjacent cylinder and from this rubber cylinder imprinted on the paper.

The art and practise of lithography is based on the well-known fact that oil and water do not mix. The art was discovered, or invented, over a hundred years ago by a Bavarian, Senefelder, who, though lacking the modern mechanical and photographic aids, seems to have practically perfected the art, so that it stands as one of the few arts that came into being almost full-grown.

Senefelder discovered that a certain kind of limestone would absorb or retain on its surface both water and certain oily or greasy inks or crayons. He drew his designs in greasy inks on the level and polished or slightly roughened (grained) surface of the stone, then coated the whole with a thin film of water. Paper was pressed against the stone in a hand press and a picture so made, following which the stone was repeatedly reinked, the oily ink merely adhering to the design, and not at all to the wet or undrawn portion, so that many proofs or reproductions of the original could be made.

This is a very crude description of the rudiments of the early process. The chief improvements since Senefelder's day are the transfer process, photo-lithography, multicolor process, offset process, and mechanical improvements in machinery.

Early lithography was largely used for the repro-

duction of artists' drawings or paintings, and the number of copies desired was few. The work was done on hand presses, and six hundred copies a day was fast work. Today lithography is an extensive and growing industry, unable to meet the country-wide demand for commerical illustrative work in natural colors.

Stone litho presses give the finest results, but print slowly, 1200 to 1500 sheets per hour, and are best adapted to coated paper.

Rotary litho presses do similar work of not quite so high a grade, but at a higher rate of speed, 1800 to 6000 per hour, and in two or more colors at one passage of the sheets, whereas stone presses print only one color at a time. Some rotary presses constructed by the American Lithographic Company printed in six colors on one side and black (type matter) on the reverse.

Rotary offset presses are used chiefly with rough or uncoated stock and produce effects in tone, texture and shading at high speed, as fast as the straight rotary presses. Recently, successful work has been done with coated paper on offset presses.

Motor Requirements of Lithographic Presses

Stone Presses. These presses involve the transfer of the rotary motion of the driving pulley into the reciprocating movement of the bed that carries the stone. A crank movement is employed, with rack and gear. The bed is supported on anti-friction rollers. The load is due to the gear and bearing friction, and to the pressure between the impression cylinder and the stone. The load fluctuates with each reversal of the bed, and increases with increasing speed somewhat faster than the speed. Phase-wound a-c. motors and compound-wound d-c. motors are recommended. Frequent starting and stopping is required. Constant-speed motors are sometimes employed, where a fixed rather low speed of printing is satisfactory. The power requirements of stone presses vary from 2 to 7½ h. p. As commercially constructed, belt drive is employed and rather low-speed motors are necessary. A reverse-point at low-speed is desirable for "backing up".

Rotary Litho Presses. The power requirements of both direct-rotary and rotary-offset presses are similar. The motion is a continuous rotary one, and the load is uniform, varying with the speed at a little faster rate than the speed increases, and varying also with the viscosity of the ink and the impression pressure. These presses are very often fitted with automatic feeders, and should the sheet of paper, as it is fed from the pile into the press, jam the mechanism, it is essential that the press be stopped quickly. This is accomplished by a "feeder-trip" switch which opens the line contactor on the motor controller. A variation involves the automatic slowing down rather than stopping when the feeder jams. A dynamic brake is necessary; on a-c. motors a solenoid brake or its equivalent is usually fitted to the motor shaft.

Both d-c. and a-c. motors are successfully used on litho presses, the a-c. motors having phase-wound rotors, and adapted to run continuously at any speed between full speed and half speed; and the d-c. motors being adapted to an equal range of 2 : 1, this being

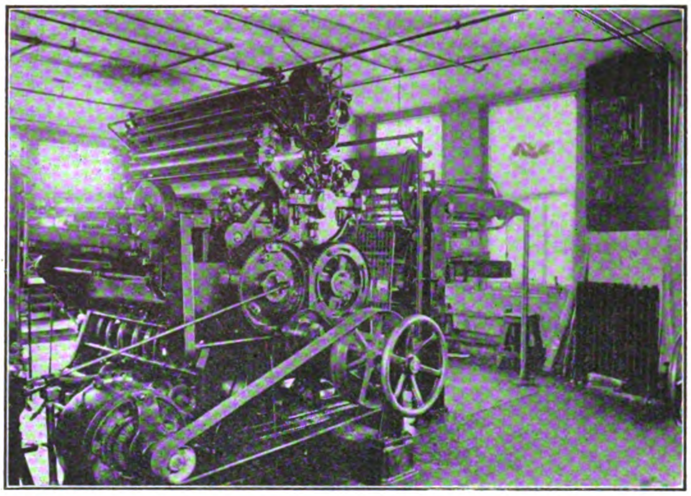


Fig. 1—Rotary Offset Press With Motor Drive. The Push-Button Operated Controller is on the Wall

preferably a combination of about 35 per cent reduction by armature control and about 40 per cent increase by field control. Frequent jogging or "inching" is required during the make-ready periods. A back-up is occasionally, but seldom used. As these presses are sheet-fed, they do not require a special very low speed for "threading-in", as do roll or web-fed rotary

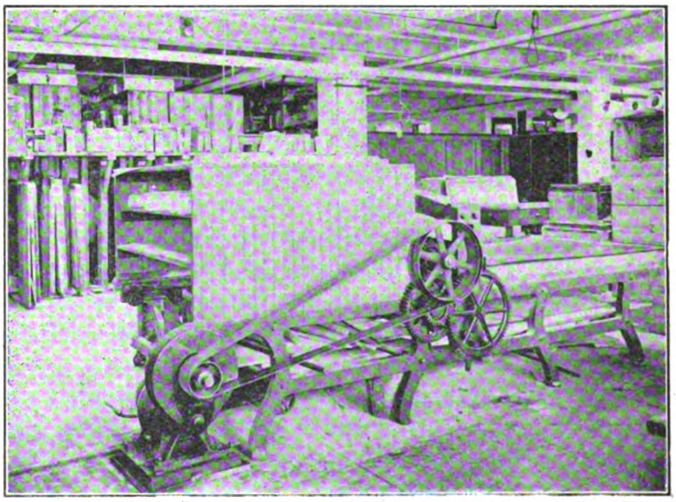


Fig. 2—Litho Transfer Press Equipped With Back-Geared Motor

presses. Power requirements vary with the size of the sheet, number of colors, and speed of production from 2 to 15 h. p.

In the processes leading up to lithographic printing, comparatively little machinery is employed, compared to stereotype or electrotype printing. There are today

a number of different processes employed in reproducing the original drawings on the stone or metal plate. In some of the processes photography is employed, in others not. In one process, the straight lithographic, the artist makes his original drawing with ink or crayons on a lithographic stone. This drawing is used as a master. For actual printing the design is reproduced, either on another stone (sometimes several times on one large stone) or on a metal plate, by the transfer process. A sheet of thin specially prepared paper, called transfer paper, is laid over the original and rolled down to close contact in a transfer press. It is then carefully removed, carrying with it the design reversed. This transfer paper is then laid down on the printing stone or plate and rolled into contact with it, the transfer press being again used. After this the artist goes over the transfer sheet, working on the back of the paper with knife and stipple to get a perfect reproduction. The registering is important, as the design may require printing in many colors on different stones or plates, which must register in final printing. The paper is then moistened and removed, and the design remaining on the stone or plate is fixed by a solution of nitric acid and gum-water.

The smaller transfer presses are hand-operated, the larger ones motor-driven.

Motor-driven transfer presses take from one to three h. p. The operation involves a rack-and-pinion movement for moving the stone carrying the transfer paper under a roller and back again. As the bed can readily be moved by hand when the impression is off, a constant-speed, nonreversing motor is sometimes employed, the motor being stopped at the end of the travel of the bed, the impression lifted by a lever, and the bed returned by turning a hand crank.

A better application is that of a reversible motor with a spring-return reversible controller—that is, a controller which returns to the off position whenever the operator releases the handle. Limit switches at either end of travel are a valuable precaution. The reversible motor allows of taking an impression each way. The load is not fully applied till after the motor starts. Back-geared motors will usually be needed, because of the low speed of the driving pulley, which turns not much faster than a man would turn a crank— 50 to 100 revolutions per minute.

In photo-lithography, the original is photographed on a glass or film negative and a print made from this directly on the stone or plate, the surface of the latter having been sensitized with chromate of potash, which develops out as in ordinary photography, and which is further fixed with the proper solution. In photo-lithography screens are interposed to give fine dots or cross-lines to aid in bringing out the final design in form to receive and hold the ink. In photo-lithography in colors, color-screens are used, so that several negatives can be made, each with the proper portions brought out which are to receive the particular color, there being as many stones or plates as there are colors to be used.

Electricity for lighting in the lithographic process is of great importance. There must be arc or incandescent lamps for the cameras used in photography. There must be light for the artist of just that value which enables him to select his colors and touch up his drawings properly.

In the preparation of the stone, machinery is employed. Stones were formerly polished by hand, with pumice-stone blocks and fine sand or ground flint. The stone-shaving machine described below first came into use to be followed by a stone-grinding machine, employing a polishing or grinding wheel in the form of a stone revolving on a vertical shaft and requiring 3 to 5 h. p. for operation. Because of uneven work and a tendency to scratch on the grinder, the stone-planing machine has come back into favor, except for small stones where a flat, revolving grind-stone is used. The stone-shaver has a screw-driven reciprocating bed, which carries the stone under a knife that takes off a very thin cut at each forward stroke.

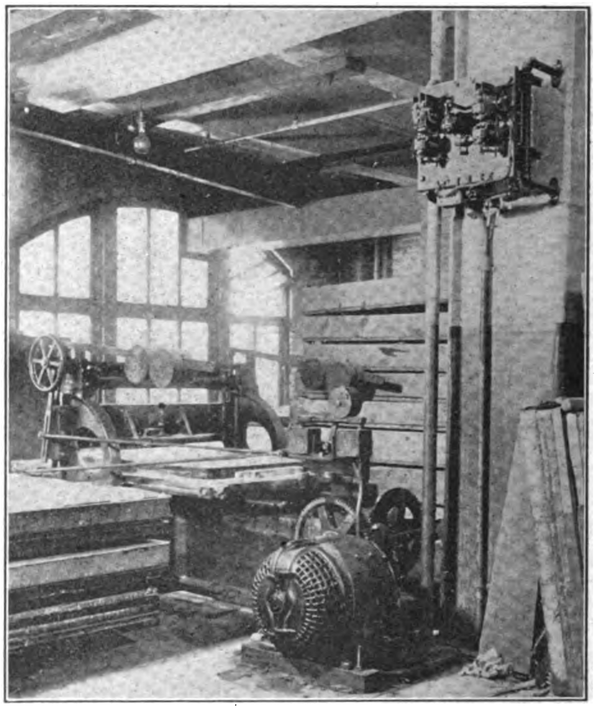


Fig. 3—Stone-Planing Machine Equipped With Direct-Geared Motor and Automatic Reversing Controller

The operation of the stone-planer is not unlike that of a metal-planer. The machine bed carrying the stone is driven back and forth under a cutting knife. the return stroke being preferably at a speed 75 per cent faster than the cutting stroke. The process is automatically repeated till the work is accomplished; hence means for automatically reversing the bed is necessary. The stone-planer may be driven by either alternating or direct-current motors. If alternating, a two-speed (pole changing) motor may be used, with

high-speed connections on the reverse, or, if the time element is not important, the quick return may be dispensed with and a single-speed motor used. Direct-current motors should be compound-wound, and preferably capable of 75 per cent increase in speed by field control in one step. The bed motion of the planer is that of a screw and traveling nut. The motor is preferably geared to the driving-shaft, and a controller for reversing the motor and cutting in the high speed on reverse should be connected to the bed motion in such manner as to be actuated by the bed travel and throw over to reverse position automatically. Either the main control switch or a master controller may be so used.

The zinc or aluminum plates used on rotary litho presses are thin enough to be bent readily to the curvature of the press cylinders and elastic enough to flatten out on removal. The plates are prepared for use by graining, a process in which the plates are set in a wooden box which is given a system of horizontal vibrations by motive power from a ½-h. p. constant-speed, continuous-running low-speed motor, so as to keep in motion a quantity of very fine balls of glass, steel or marble mixed with powdered flint, which roughen up the plate surface. The same process is used to regrain the plates after the run has been made, to prepare them for new work.

Closely allied to lithography are three processes needed to complete certain classes of work, especially fancy colored labels, such as cigar labels. Cigar labels are lithographed on stone, the original design being reproduced many times on the stone by repeated transfers, so that the finished sheet carries several hundred labels. This sheet requires bronzing, embossing and cutting, all of which are machine processes.

A bronzing machine is one in which lithographed sheets are coated with bronze dust, which adheres only to those portions of the design which have previously been printed in a special bronze-colored oily ink—namely those portions which are to have a "gold" appearance in the finished product. The sheets are fed into the machine as into a printing press, and bronze dust is distributed over them by a revolving brush. The dust does not adhere to the colored (non-bronze) portions of the design, but its presence on the bronzed portions gives a luster not obtainable from the ink itself.

The load imposed on the driving motor of a bronzing machine is uniform, the torque required at different speeds being substantially constant. The smaller bronzers are run at constant speeds, the larger ones at varying speeds. Direct-current motors with armature control and polyphase motors with wound rotors operate satisfactorily in this application. The service is non-reversing, requires infrequent starting and stoping, and the speed range is less than 2:1. Several bronzers are so built as to require a separate small constant-speed motor for driving an exhauster. Bronzers take from ½ to 3 h. p. Though generally individually driven, they are sometimes driven by the printing press on which the sheets have been printed, so as to synchronize with the presses and complete the printing and bronzing in substantially a continuous operation. This is accomplished by a chain drive extending between the two machines, and a delivery attachment on the press which feeds into the bronzer.

The embossing presses for this work have dies which register with those portions of the design which are to be raised. The sheets are fed into an embosser as into a printing press, and as each sheet comes under the platens or dies, some of which are usually heated, it is subjected to pressure like that of the steel sheets in a forming press; and the finished sheet is then delivered with the designs raised as desired. The pressure is applied either by a crank or eccentric movement or by toggles, power being supplied by a

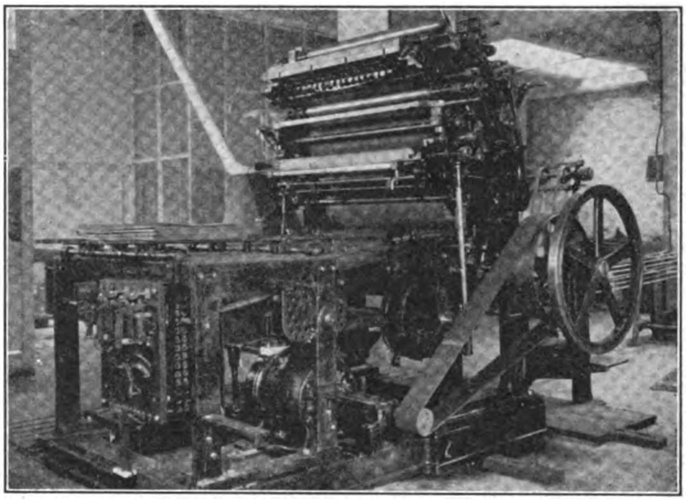


Fig. 4—Rotary Metal Decorating Press Equipped With D-C. Motor and Push-Button Operated Controller

motor of from 2 to 15 h. p., depending on the size and pressure. A large flywheel on the embosser takes up the load at the instant of applying the pressure.

The operation of the machine is not dissimilar to a metal punch press. The starting effort is involved chiefly in accelerating the flywheel, as the embossing work proper is done by throwing in a clutch after the motor is up to speed. Hence the motor speed control does not involve jogging or dynamic brake, but it does involve a speed range of 1½:1 or 2:1, as the number of sheets per minute which can be fed into the embosser will vary with the stock, size, grade, etc. On a-c., motors with phase-wound rotors have been successfully employed, and on d-c., armature control can be used, though field control is usually preferred. Belt drive is almost always employed.

The cutting machines in a lithographic plant may be straight power cutters (guillotine cutters), as used for cutting sheets in piles in all kinds of printing and paper-product manufactures, or cutters fitted with

cutting dies of special design, such as are obviously required to give the conventional shape to cigar labels. The operation of these die cutting machines is very similar in principle to that of the embosser, but less pressure is required and relatively smaller motors are needed and the work is all done at one speed.

In printing on tin plate a press called a metal-decorating machine is used, the process being essentially a surface printing process, in which the printed sheets are given a coating to receive the printing. The work must obviously be done at low speeds, as tin plate cannot be fed as fast as paper sheets. But little machinery is used in the process aside from the press itself, which may take three to five h. p., and the forming and cutting machines which produce the metal container from the flat sheet. After printing, the sheets are varnished and baked to fix the ink.

SUBSURFACE PRINTING

Steel Plate Engraving

The Process. The first engraving was done by skilled artists, who depicted their subject by cutting into a soft steel plate with a fine hardened tool. Today after hundreds of years, the process continues to depend on the skill of the engraver. Prints were made directly from the early plates. They were almost all pictures, and a few copies were needed. Today engraving is a specialized commerical enterprise and thousands of imprints are required. Means have been devised for reproducing the plates and for printing from copies at high speed—relatively high speed, that is, for the speed of plate presses is less than of type or half tone presses or offset presses.

The reproduction of the original plate is carried out in two ways: In the first processes the original plate is hardened and a soft plate is pressed into its depressions. This soft plate is then hardened, and still another plate is pressed over its raised lines. Finally, this last plate is hardened and used for printing. The process is called "transferring" and requires a very powerful hydraulic press. The plates actually used for printing—as many as may be required—are left flat or bent to a curve, according as they are to be used on flat-plate or rotary presses.

The second process, the "electrolytic", involves the filling in of the engraved lines of the original with a copper coating, which is gradually reinforced till it becomes a solid plate, called the "alto." The surface of the original is of course treated to prevent adhering of the copper deposit. From the alto, also by electrolytic process, the "basso," is made, from which the actual printing is done. The electrolytic process employs a 6/12-volt plating generator, of 1000 to 3500-ampere capacity, depending on the amount of work to be done.

Engraving is used by our government for all forms of paper currency; bonds and all government securities; postage stamps; letterheads and important business forms. It is used by the commercial firms engaged in similar work—for stock certificates, bonds, and all negotiable instruments where protection against counterfeiting is of importance.

A simpler form of engraving, involving less process work, is that employed for business cards, invitations, announcements, letterheads, etc. (Die Presses).

The printing process involves inking, wiping or polishing; taking the impression; drying and removal.

The simplest power-operated engraving press is the electrified hand press, used by the Bureau of Engraving and Printing. These presses take a 9 by 13 sheet, are operated by a ¾-h. p., 1350-rev. per min., compound, constant-speed, reversible d-c. motor, and print about 12 sheets a minute.

The next important engraving press is the continuous-feed power-plate press, in which four plates, each taking a 20 by 21 sheet, are caused to travel about a square, each plate in turn being inked, wiped, fed with a sheet, printed, and the sheet removed. The speed is from 900 to 1400 sheets per hour. A five-h. p. compound d-c. motor is used, with 50 per cent field control. The motor speed may be 500/750 or 875/1325 according to the make of press. A predetermined speed or full-automatic controller is employed. Dynamic brake, giving a very quick stop, is essential. Both gear and belt drive have been used.

A rotary plate press is used for postage stamps. It is fed from a roll and prints the stamps on a continuous web, which is afterwards gummed and perforated. Rotary engraving presses are also used for bonds, stock certificates, etc., and could undoubtedly be used for paper currency, although practise has confined this work to the slower flat-plate machines.

The rotary presses used for engraving work have been usually built to order, and there is no general standard. Most of those constructed will come within a range requiring, for the smallest 3 h. p., and for the largest 10 h. p. The motors should have from 50 to 75 per cent field control, be compound-wound, non-reversible, with predetermined speed or full-automatic control, and dynamic brake. Gear drive is employed.

Die Presses. These presses are so called because the plates from which the impression is made is usually called a die. Commercial die presses are built in sizes ranging from a 2 in. by 4 in. card to a 6 in. by 10 in. card, requiring from ¾ to 3 h. p., depending on the size of the machine. Die presses operate on either the crank (or eccentric) action or the toggle action to give the necessary pressure to force the paper or card a little into the depressions in the plate. A clutch is employed for throwing in the action of the machine.

It is customary with die presses to employ compound-wound d-c. motors with 50 per cent field control and 40 per cent armature control, using predetermined speed type self-starting controllers. On alternating

current, two or three-phase varying-speed wound rotor motors are successfully employed.

It may be here stated that, while no mention of alternating-current motors was made in connection with rotary and flat-bed steel-plate presses, this is simply because the engraving business is a close industry and the few large plants use d-c. motors entirely. There is nothing in the engraving press which makes its operation by varying-speed wound rotor polyphase motors any more of a problem than that involved in operating type presses; and type presses of all kinds are very successfully operated in great numbers with a-c. motors.

ROTOGRAVURE

The rotogravure process was developed in Germany, and the first rotogravure presses used in the United States were built there. The process is a development of the photogravure process, a process in which a design was photographed on copper plate and the lines necessary to reproduce the picture etched below the surface so as to receive the printing ink as in direct hand engraving. It is the opposite of the half-tone process, in which the inked portions are raised above the surface. It is intaglio, and not cameo, printing; and, in fact, the presses are sometimes called intaglio presses. The process was the result of efforts to put photogravure on curved plates or cylinders and to run them at high speed with a continuous roll or webb, as in a newspaper press.

A rotogravure press is very like a rotary web magazine or newspaper press in general appearance. It ordinarily has one deck, feeds from one roll of paper, prints on both sides at one passage of the web, using two printing cylinders. The speed is low compared to newspaper printing (stereotype), or about the same as high-grade magazine work—about 4000 an hour, but work has been done at a rate as high as 10,000 cylinder revolutions per hour. One factor limiting the speed is the time to dry the ink between impressions. The ink is quite different from ordinary printing ink. It has a petroleum base and it is quite volatile. Special drying apparatus is required.

The printing is done from continuous copper-sheathed steel cylinders instead of plates, the cylinder with its shaft or arbor being substantially one solid mass. It is prepared by copper-plating the steel core. After use the cylinder is turned down to a new surface. Eventually it must be replated. Formerly the copper cylinders were cast hollow, turned up inside, and forced over the arbor by hydraulic pressure. The present system takes much less work.

In the process, the copy is prepared first—photographs, drawings, type matter, etc. The copy is then photographed to the proper size on a glass or a film, making a negative. A print is made from the negative on a sensitized carbon paper that has been screened, giving the proper cross-lines. This carbon paper print, having been developed, is laid against the copper cylinder, registered as to position, and rolled up to give close contact. Hot water is then applied to soften the paper, which is then offset, leaving an impression on the cylinder. This impression is then etched in with acid to the desired depth. The film is then washed off with turpentine or similar reagent, leaving a perfectly engraved surface ready for printing.

In the press the copper cylinder is in direct contact with the ink at one segment of its circumference. A soft metal knife, oscillating back and forth, clears off all the ink except that which remains in the engraved or subsurface lines.

Rotogravure presses, in common with other rotary web presses, require a specialized form of motor drive. The cylinders must be revolved at a steady, low speed of 8 to 10 rev. per min. for threading in the paper. They must then be accelerated smoothly and evenly to 80 or 100, or even to 165 rev. per min. for printing. The speeds must be capable of variation through a considerable range, so as to get the maximum speed which any given stock of paper, under any of widely different conditions, may admit. The torque increases somewhat more rapidly than increase in speed, the load consisting of gear and bearing friction, cylinder pressure, paper tension, action of the folder (if used), and the resistance due to the viscosity of the ink.

Automatic push-button control is generally employed. Quick stop is important, and a device for stopping in case the web breaks is desirable. Rotogravure presses have been constructed taking as little as 5 h. p., and others taking as much as 40 h. p. On the larger presses a two-motor drive is used, consisting of one main driving motor for running the press on speed and one starting motor, one-fifth or one-eighth the size of the larger motor, for starting and threading. The starting motor is connected to the press through slow-motion gearing, and with an automatic over-running, throw-off clutch which disengages the starting motor when the press shaft is driven above the starting speed by the large motor. The smaller presses may, when direct current is available, be operated successfully by a single motor, using a speed range of 3:1 by field control and a low speed by armature resistance of one-fifth of normal. On alternating current, however, the two-motor drive is recommended, down as small as 7½ h. p.

MOTOR FOR SUBSIDIARY PROCESS—ROTOGRAVURE

Copper Plating. The steel printing cylinders are covered with a copper sheath about ¼ to ⅜ in. thick in an electroplating bath, the standard copper-plating process being used. Six volts is ordinarily employed, the current varying from 1200 to 2500 amperes according to the amount of work to be done, number of tanks, etc. The plating generator is usually direct-coupled to a constant-speed motor.

As in the electrotyping processes, water and air

pumps are required to keep up the water supply in the tanks and to agitate the electrolyte. The former may be, the latter always, is required. Manufacturers of electroplating supplies list water pumps of from 10 to 100 gallons per minute capacity and taking from $\frac{1}{4}$ to 5 h. p. Positive-pressure air pumps, for keeping the bath in constant commotion, are listed in capacities of from 20 to 300 cu. ft. per min. and requiring from $\frac{1}{4}$ to 10 h. p. Speed variation of $1\frac{1}{2}$:1 or 2:1 is desirable, to regulate the volume. The pressure will vary from one to five lbs. per sq. inch.

When the cylinder has been built up to the required thickness of copper, it is turned down true in a special lathe, and the same tool is used to take off the etching after a run is completed, to prepare the cylinder for new work. This process is repeated till the cylinder is too thin, and then it is built up again in the copper bath.

The lathe is driven by adjustable speed motor of approximately three h. p., for a lathe taking a 70 in. cylinder; 3:1 speed control is desired. The cuts taken are light and the work done is relatively small and the friction load relatively large, the lathe being of heavy construction because of the weight and length of the cylinders.

On the rotogravure press itself, the adjustment of the bearings is essential because of changing diameter of cylinders with the turning down of the copper sheath. This adjustment is accomplished in some makes by motor driven screws, one under each bearing, and geared together. A small series-wound motor, about $\frac{1}{2}$ h. p., is employed for this service.

Drying of the ink is, as mentioned above, of prime importance. Electric heat has been successfully applied for this purpose. The web is passed in front of a large flat heating element, which may consume as much as 10 kw.

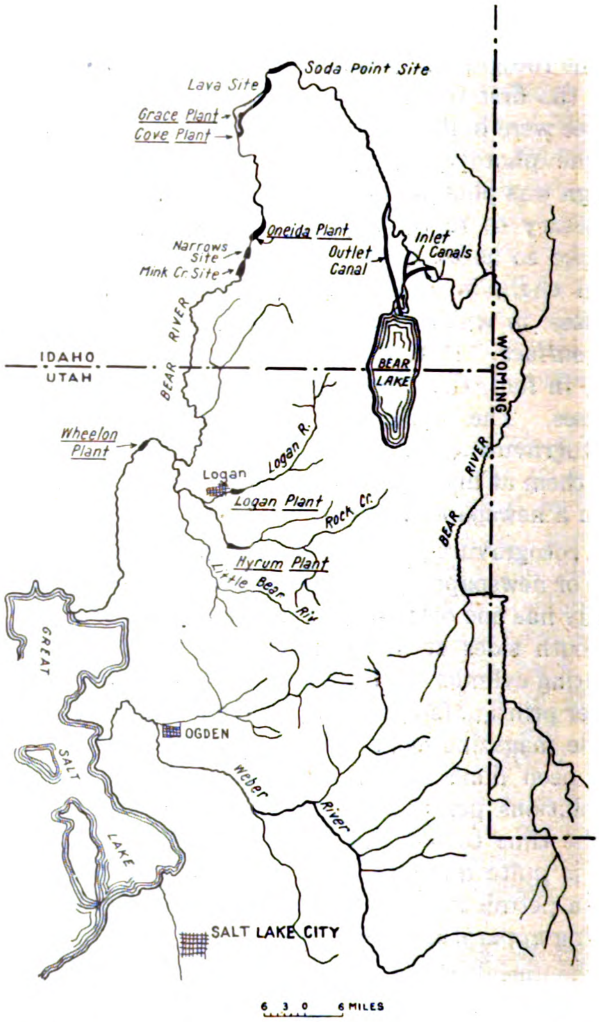
HYDROELECTRIC ADDITIONS TO THE UTAH POWER AND LIGHT COMPANY

Unusual interest attaches to the plans of the Utah Power and Light Company, under preliminary permit issued by the Federal Power Commission last July, for extensive power developments on Bear River in southeastern Idaho.

The completed project will add 21,500 horse power of hydroelectric energy to the generating capacity of the company's system, now capable of developing about 165,000 of hydroelectric horse power, and will be connected with the big main transmission system operating at 130,000 volts, extending from Grace plant, in Idaho, to Salt Lake City, a distance of 134 miles, and supplying a population of 300,000 with power, much of which is used in mining and manufacturing.

Bear Lake, 135 square miles in area, lies in a basin tributary to the river near the Idaho-Utah line. The Utah Power & Light Company now diverts the flood waters of the river into the lake and at seasons of low water draws them back into the river. By release of this stored water the amount of power available is increased, and a great improvement in irrigation is effected.

At Soda Point, about 36 miles below Bear Lake Reservoir, the river enters a canyon and descends swiftly to Logan Valley. In this stretch the company now has three hydroelectric plants, with a combined capacity of 94,300 horse power. Farther down, at



Utah Power and Light Company's New Developments on Bear River

Wheelon below Logan Valley, a fourth plant is located which can develop 9550 horse power.

Developments under the Commission's permit will be confined to four locations above Logan Valley. The two upper sites will have effective heads of 75 and 85 feet and each will have a primary capacity of about 6500 horse power. The two lower sites will be located immediately below the existing Oneida plant, and will develop about 9800 horse power.

Shunting Characteristics of the Relay in an A-C. Track Circuit Employed in Railroad Signaling

BY C. F. ESTWICK

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It is usually the practise in railroad signaling to automatically control the operation of signals and other safety devices in the system by means of a relay operated in an electrical circuit which is completed through the rails of the track. The track is sectionalized by placing insulated joints in the rails so that each section becomes insulated from adjoining sections. The rails are utilized throughout the entire length of a section as conductors for carrying current from a source of energy located at one end of the section to the track relay at the opposite end. The relay operates in a closed circuit and is normally energized. When a train enters a track section the wheels and axles of the cars form a conducting path for the current to flow directly from one rail to the other instead of flowing through the relay. This shunts the relay sufficiently to cause it to release its contacts thus allowing the signals to operate in such manner as to indicate the presence of the train. If the relay fails to shunt with a train in the section the signals not only fail to protect the train, but give false indications advising approaching trains that the track is clear. Continuous track circuits as they are employed in the present state of the art are recognized as the safest means of controlling signals, but even so where they are used the integrity of the entire signaling system is dependent upon the proper functioning of the track relay. It is therefore important to study the various characteristics of the track circuit particularly in connection with the shunting action of the relay.

Much consideration has been given to the question of shunting, more especially where the track circuits are operated with continuous current, and a great deal that has been developed in connection with continuous-current circuits applies to the alternating-current track circuit. There are also conditions that exist in a-c. track circuits that are due to the use of alternating current and to the characteristics of the different types of a-c. relays employed. The track relays that are mostly used in a-c. signaling are "two-phase" relays which have one phase, or group of windings, connected to the track and the other phase supplied with energy from a separate transformer. It is the intention in this discussion to consider the induction motor type relay which consists of a contact mechanism operated from the shaft of a motor of special design. The motor has a nonmagnetic rotor acted upon by a stator which is wound similarly to that of an ordinary two-phase induction motor. The two sets of windings of the stator are connected to separate terminal posts, one set constituting the track phase and the other the local phase. The track phase is wound to a low impedance which depends upon the conditions of the track circuit, whereas the local phase is wound to a higher impedance which is determined by the power required in the windings and the voltage available at the transformer.

The characteristics of the relay are as follows:

(1) If the local phase is constantly energized and the phase displacement between the current in the track and local phase windings is constant the torque developed at the rotor shaft varies directly as the current in the track phase.

(2) If the current in both the track and local phase windings are constant and the phase displacement is varied the torque will vary directly as the sine of the angles of displacement. When the phase displacement is 90 deg. the torque is a maximum, and when it is 0 deg. or 180 deg. the torque is zero.

(3) When the current in the track phase leads the current in the local the torque tends to operate the relays in one direction, and when it lags behind the local current the tendency is to operate in the opposite direction.

In making laboratory or shop tests on a relay, means are generally available for varying both the size of the currents in the windings and their phase displacement. It is usual to make shop tests at 90 deg. phase displacement and describe the operating characteristics of the relay accordingly.

In operation in a track circuit the phase displacement of the currents in the windings may be poor, in some cases probably less than 20 deg., whereas in other cases it may approximate 90 deg. or it may be more than 90 deg. This depends upon the length of the track section, the impedances in the circuit and the resistance of the ties and the ballast. In the same track circuit the current in the track phase of the relay and the phase displacement are found to vary on account of changeable weather conditions which cause a considerable variation in the ballast resistance. When a train enters a track circuit the application of the shunt across the rails decreases the current in the relay and causes a change in the phase displacement. If the effect is such as to increase the phase displacement the current will have to decrease more than would otherwise be necessary to cause the relay to release its contacts, but on the other hand if the phase displacement becomes less the relay will release its contacts with a smaller decrease in current. It is therefore necessary to consider vector values of the currents in order to understand the effect of a shunt on the operation of the relay.

Where there is a switch in a main track that leads

to a branch track or at a cross-over it is practise to install a switch circuit controller which is operated mechanically by the throwing of the switch. The circuit controller is provided with contact fingers that are wired to the rails and are operated in such manner that when the switch is open the rails become short-circuited. The shunt through the contact fingers is usually of a much higher resistance than that obtained through the wheels and axles of a car or locomotive. At switch locations the rails on the main track are bonded to those of the turn out in such manner as to carry the track circuit out at least as far as the fouling point. It sometimes happens that the rails leading to a siding that is not much used become rusted to such an extent that very poor contact is made between the rails and the wheels of a car standing on the track. It is evident that a relay is expected to release its contacts when the shunt across the rails is of a comparatively high resistance. The relay that affords

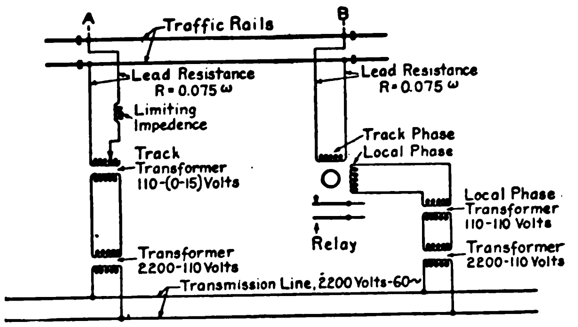

Fig. 1—Typical A-C. Steam Road Track Circuit

the greatest factor of safety in operation is that which will shunt with the highest resistance connected across the rails. The quality of the shunting in a track circuit is measured by the maximum shunting resisttance that will cause the contacts of the relay to open. The effect on the relay, of course, varies with the position on the track at which the shunt is applied. In some track circuits the relay will shunt better when the shunt is applied at one end of the track and in others when the shunt is applied at the opposite end. In considering the shunting characteristics of a track circuit the maximum shunting resistance should be determined for shunting at both ends of the track.

The circuit diagram shown in Fig. 1 is a typical steam road track circuit supplied with alternating current at 60 cycles over a high-voltage transmission line. The transformer that supplies energy to the track is provided with taps on the secondary winding arranged so that the voltage can be adjusted in steps of 1 volt up to 15 volts. The relay shown is of the type already described and has the local phase supplied with energy at 110 volts.

The characteristics of the windings are as follows:

Local phase: 110 volts, 0.252 ampere, 18 watts.
27.7 volt-amperes, 437 ohms impedance
0.65 power factor.

If Z_{L0} represents the impedance and I_{L0} the current in the local phase with reference to the voltage at the transformer these values may be written:

$$Z_{L0} = 437 \angle 49^\circ.5 \text{ ohms}$$

and

$$I_{L0} = 0.252 \nwarrow 49^\circ.5 \text{ ampere}$$

Track phase: 0.64 ohm impedance
0.602 power factor

This impedance may be represented by Z_R and expressed:

$$Z_R = 0.64 \angle 53^\circ \text{ ohm}$$

The operating characteristics of the relay when tested at 90 deg. phase displacement with the local phase constantly energized are:

Current that causes the relay to pick up to just close its front contacts, $i_c = 0.19$ ampere.

Current that will pick up the relay to its front stop $i_m = 0.22$ ampere.

Current that allows the relay to release its contacts $i_d = 0.115$ ampere.

The above current values and all currents and voltages referred to hereafter will be understood to be effective or r. m. s. values.

The limiting impedance Z_l connected in the circuit between the transformer and the rails is adjusted to 3 ohms with a power factor 0.174, *i. e.*

$$Z_l = 3 \angle 80^\circ \text{ ohms}$$

The leads connecting the relay to the track and those between the transformer and track have a resistance $R = 0.075$ ohm.

The impedance of the receiver Z_B equals the impedance of the relay and leads to the track, and the impedance of the total limiting impedance Z_L includes the resistance of the lead, thus

$$Z_B = Z_R + R = 0.68775 \angle 48^\circ.004 \text{ ohm}$$

and

$$Z_L = Z_l + R = 3.0139 \angle 78^\circ.596 \text{ ohms}$$

The voltage at the track transformer is adjusted to 7 volts.

Properties of the track: Length of section $L = 9000$ feet.

The rails are 90 lb. per yd., A. S. C. E. section bonded with 2 No. 6 A. W. G. copper-clad bond wires at each joint. The impedance of the rails is 0.3 ohm per 1000 ft. and the power factor 0.866. The ballast is stone and is about 50 per cent clear of the base of the rails. The resistance of the ballast varies from 5 ohms to 20 ohms per 1000 ft. depending upon weather conditions.

The impedance of the rails and leakage conductance during rainy weather conditions are:

$z = 0.3 \angle 30^\circ$ ohm, loop impedance of the rails per 1000 ft.

$g = 0.2$ mho, conductance of the ties and ballast per 1000 ft.

In the present instance the rail impedance and ballast conductance are assumed to be evenly distributed along the track.

The attenuation constant α and the surge impedance of the track z_0 may be determined from the formulas:

$$\alpha = \sqrt{z\,g} \quad \text{and} \quad z_0 = \sqrt{z/g}$$

whence $\alpha = 0.24495 \angle 15° = 0.23660 + j\,0.06340$ hyp

and $z_0 = 1.2247 \angle 15°$ ohms

The hyperbolic angle that corresponds to any length of track varies directly as the length. The angle α corresponds to unit length of track, therefore the angle θ which corresponds to the length of track L, from A to B, equals $L\,\alpha$ or

$$\theta = 9\,\alpha = 2.1294 + j\,1.0647 \text{ hyps.}$$

Most of the problems that arise in connection with the track circuit can be most easily solved by the method of first determining the position angles at different positions on the track and then expressing the relations between the currents, voltages and impedances in the circuit in terms including the surge impedance and functions of the position angles. In studying the conditions at the relay and transformer ends of the circuit it is only necessary to determine the position angles δ_A and δ_B for the positions A and B at the ends of the track section. These position angles are determined from the equations:

$$\delta_B = \tanh^{-1} Z_B / Z_0 \quad \text{and} \quad \delta_A = \delta_B + \theta$$

The position angles and the following functions have been computed from the above relations by employing well-known formulas:

$$\delta_B = 0.44976 + j\,0.36460 \qquad \delta_A = 2.5792 + j\,0.93518$$

$$\sinh \delta_B = 0.58604 \angle 42°.147 \qquad \sinh \delta_A = 6.6045 \angle 53°.896$$

$$\cosh \delta_B = 1.0436 \angle 9°.143 \qquad \cosh \delta_A = 6.5821 \angle 53°.266$$

$$\tanh \delta_B = 0.56155 \angle 33°.004 \qquad \tanh \delta_A = 1.0034 \angle 0°.630$$

The currents and voltages in the circuit may be expressed as complex quantities or described graphically as "plane vectors." If the voltages at the secondaries of the transformers supplying current to the track circuit and to the local phase of the relay are assumed to be in phase these voltages may be selected as the standard phase and described as having a slope $\angle 0°$. All other currents and voltages will then be expressed to show their phase with reference to the voltages at the transformers. The voltage E at the secondary of the track transformer may therefore be written:

$$E = 7 \angle 0° \text{ volts}$$

If a shunt having a variable conductance G_S is connected across the rails of the track the relation between G_S and the current I_S in the track phase of the relay may be expressed by the equation:

$$G_S = \frac{E\,Y}{I_S} - K$$

This equation applies generally to the steam-road track circuit or to the electric-road track circuit where impedance bonds are employed to provide for the return of the propulsion current. It also applies whether the shunt is connected at either end of the track or at some intermediate position. The first term of the second member represents the admittance of the entire circuit between opposite points on the track where the shunt is applied, and the second term represents the same admittance less the conductance of the shunt.

When the shunt is applied at the A end of the track the values of Y and K are expressed in the following equations:

$$Y = \frac{\cosh \delta_B}{Z_l\,Z_0 \sinh \delta_A}$$

$$\text{and} \quad K = \frac{Z_l - Z_0 \tanh \delta_A}{Z_l\,Z_0 \tanh \delta_A}$$

The values of Y and K have been computed from these equations and are as follows:

$$Y = 0.042808 \angle\!\!\!\!\smallsetminus 138°.349$$

and $K = 0.84924 - j\,0.54447 = 1.0088 \angle\!\!\!\!\smallsetminus 32°.665$

Before proceeding with the question of the shunting it may be well to consider the conditions in the circuit before the shunt is applied, that is, when the section is unoccupied by a train. In this case $G_S = 0$ in the above equation. If the current in the track phase of the relay is represented in this case by I_B the equation becomes

$$I_B = \frac{E\,Y}{K}$$

The value of the current as obtained from this equation is:

$$I_B = 0.29703 \angle\!\!\!\!\smallsetminus 105°.684 \text{ ampere}$$

If γ represents the slope of the current in the track phase, β the slope of the local phase current and ϕ the phase displacement,

$$\phi = \beta - \gamma = \angle\!\!\!\!\smallsetminus 49°.5 - \angle\!\!\!\!\smallsetminus 105°.684 = +56°.184$$

The current i at 90 deg. phase displacement that gives operation of the relay equivalent to that obtained when I_B is flowing in the track phase equals the size of I_B, represented by $|I_B|$, multiplied by the sin ϕ, that is:

$$i = |I_B| \sin \phi = 0.24678 \text{ ampere}$$

The ratio $i / i_m = 1.122$ indicates that the adjustment of the track circuit gives satisfactory operation of the relay and provides a margin over the minimum working current i_m of about 12 per cent to allow for variations in the transmission line voltage.

The most important problem that arises in connection with the shunting of the relay is to determine the maximum shunting resistance or the minimum value of G_S which will shunt the relay so that the front contacts open. To determine the minimum value of G_S the general equation given above may be written in the form:

$$K + G_S = \frac{E\,Y}{I_S}$$

This equation may be readily solved graphically by a

construction as shown in Fig. 2. In laying out the diagram the dot and dash line $o\,L$ is first drawn at an angle $\overline{\angle}\ 49°.5$ to represent the slope of the current in the local phase. The line $o\,c$ is drawn at 90 deg. to the line $o\,L$. Then on $o\,c$ lay off $o\,d$ to a convenient scale, to represent the current $i_d = 0.115$ ampere at 90 deg. phase displacement. The line $a\,b$ is then drawn through d parallel to $o\,L$. It will be seen that any vector drawn from the origin and terminated in the line $a\,b$ has a component $o\,d$ displaced 90 deg. from the local current. All such vectors represent current values that give operation of the relay equivalent to that obtained by $o\,d$. Since all possible vector values of the current that just allow the relay to release its contacts terminate in $a\,b$ it may be said, in this sense, that $a\,b$ represents the drop-away current and this includes the current I_s. The line $a\,b$ is then inverted by drawing the circle S_1 to pass through the origin, so that its diameter lies on the line $o\,c$. The length

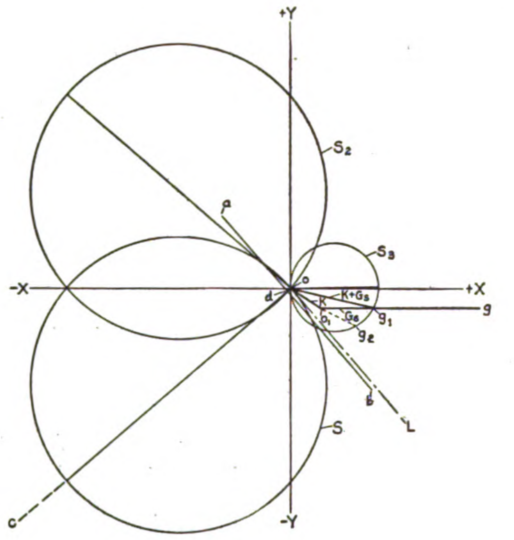

FIG. 2

of the diameter is made numerically equal to the reciprocal of i_d. The vector value of the diameter of the circle may be expressed:

Diameter $S_1 = 1/i_d \angle\ (\beta - 90°) = 8.6957\ \overline{\angle}\ 139°.5$.

The circle S_2 is drawn as the reflection of circle S_1 with relation to the horizontal axis. The vector value of the diameter of S_2 is the same as the diameter of S_1 except that the sign of the slope is changed, thus:

Diameter $S_2 = 1/i_d \angle\ (-\ \beta + 90°)$

$$= 8.6957 \angle\ 139°.5$$

The circle S_2 is the reciprocal of the line $a\,b$. Any vector from the origin that terminates in the circumference is the reciprocal of a corresponding vector drawn from the origin and terminated in $a\,b$. Circle S_2 therefore includes the value $1/I_s$. Then operating upon the circle S_2 by $E\,Y$ in such manner as to vary its size by a factor equivalent to the size of $E\,Y$ and to rotate it through an angle equal to the slope of $E\,Y$ gives the circle S_3 which represents vector values that include $\dfrac{E\,Y}{I_s}$. The diameter of circle S_3 may be expressed:

$$\text{Diameter } S_3 = \frac{E\,Y}{i_d} \angle\ (-\ \beta + 90°)$$

$$= 2.6057 \angle\ 1°.151$$

The line $o\,o_1$ is drawn to the same scale in mhos to represent the vector value of $K = 1.0088\ \overline{\angle}\ 32°.665$ A line $o_1\,g$ of indefinite length is drawn horizontally to the right from o_1, the terminus of vector K. Since the slope of conductance is assumed to be $\angle\ 0°$ this line may be taken to represent all possible values of G_s. It will be seen that any value of $K + G_s$ may be described by a vector drawn from the origin to terminate in the line $o_1\,g$, but $K + G_s = \dfrac{E\,Y}{I_s}$ therefore, the particular value of $K + G_s$ which fulfills the conditions of both members of the equation is represented by a line $o\,g_1$, drawn to the intersection of the circle S_3 with the line $o_1\,g$. By scaling the line $o_1\,g_1$ the minimum value of the conductance is found to be:

$$G_s = 1.6245$$
$$\text{or} \quad R_s = 0.61556$$

Instead of solving the problem to determine the minimum value of G_s by the graphical method the problem may be solved more accurately by employing algebraic formulas that are derived from a solution of the equation $G_s = \dfrac{E\,Y}{I_s} - K$. This solution of the equation is given as follows:

Let $I_s = \dfrac{i_d\,\epsilon^{j\gamma_s}}{\sin\phi_s}$ and let $Y = y \angle v = y\,\epsilon^{jv}$

in which $\phi_s = \beta - \gamma_s$; y represents the size of Y and ν the slope of Y.

Then by substituting these values in the general quation this may be written:

$$G_s = \sin\phi_s \,.\, \frac{E\,y}{i_d} \,.\, \epsilon^{j(v - \gamma_s)} - K$$

Multiplying and dividing the first term of the second member of the equation by $\epsilon^{-j\beta}$, the equation becomes:

$$G_s = \sin\phi_s \,.\, \frac{E\,y}{i_d} \,.\, \epsilon^{j\phi_s} \,.\, \epsilon^{j(v-\beta)} - K$$

Let $\dfrac{E\,y}{i_d} \,.\, \epsilon^{j(v-\beta)} = m + j\,n$ and $-\,K = e + j\,f$

then $G_s = \sin\phi_s \,.\, \epsilon^{j\phi_s}\,(m + j\,n) + e + j\,f$

Remembering that $\epsilon^{j\phi_s} = \cos\phi_s + j\sin\phi_s$ the latter equation becomes:

$$G_s = \sin\phi_s\,(\cos\phi_s + j\sin\phi_s)\,(m + j\,n) + e + j\,f$$

The equation is now cleared of expotential values and may be expanded and then by equating real components to G_s and imaginary components to zero the following simultaneous equations are obtained:

$$G_s = \sin\phi_s\,(\,m\cos\phi_s - n\sin\phi_s\,) + e$$
$$o \;=\sin\phi_s\,(\,n\cos\phi_s + m\sin\phi_s\,) + f$$

By solving these equations the following formulas have been derived for the purpose of determining the values of G_s and ϕ_s:

$$G_s = e - n\,/\,2 \pm \sqrt{(\,n\,/\,2\,)^2 - m\,f - f^2}$$

$$\sin^2\phi_s = \frac{-\,n\;\,G_s - e) - m\,f}{m^2 + n^2}$$

The sign be'ore the radical in the first of these equations is taken so that G_s is positive. If the value of $\beta - \gamma_s$ is negative, as is the case when the track phase current leads the local current, the last equation containing the expotential $\epsilon^{j\phi_s}$ becomes:

$$G_s = \sin\phi_s\,.\;\epsilon^{-j\phi_s}\;(m + j\,n) + e + j\,f$$

By substituting $\cos\phi_s - j\sin\phi_s$ for $\epsilon^{-j\phi_s}$ and proceeding the same manner as above the final formulas become:

$$G_s = e + n\,/\,2 \pm \sqrt{(n\,/\,2)^2 + m\,f - f^2}$$

$$\sin^2\phi_s = \frac{n\,(G_s - e) + m\,f}{m^2 + n^2}$$

These equations offer a simple algebraic solution of the general equation and may be employed as follows in working out numerical values.

The values of m and n are obtained from the equation

$$\frac{E\,y}{i_d}\,.\;\epsilon^{j\,(v-\beta)} = \frac{E\,y}{i_d}\,\angle\,(v - \beta)$$

$$= 2.6057 \nwarrow 88°.849 = 0.05234 - j\,2.6051$$

whence $m = +\,0.05234$ and $n = -\,2.6051$

The values of e and f are obtained from:

$$-\,K = -\,(1.0088 \nwarrow 32°.665) = -\,0.84924 + j\,0.54447$$

then $e = -0.84924$ and $f = +\,0.54447$

From the equation

$$G_s = e - n\,/\,2 \pm \sqrt{(n\,/\,2)^2 - m\,f - f^2}$$

the value of the conductance G_s is found to be:

$$G_s = 1.6245 \text{ mhos}$$

or

$$R_s = 0.61556 \text{ ohm}$$

The angle ϕ_s as obtained from the formula

$$\sin^2\phi_s = \frac{-\,n\,(G_s - e) - mf}{m^2 + n^2}$$

is found to be:

$$\phi_s = +\,76°.436$$

The slope of the current in the track phase of the relay $\gamma_s = \beta - \phi_s = \nwarrow 125°.936$ and the size of the current equals $\dfrac{i_d}{\sin\phi_s} = 0.11830$ ampere.

The value of the current in the track phase may then be expressed in the polar form thus:

$$I_s = 0.11830 \nwarrow 125.°936 \text{ ampere.}$$

In solving the general equation it has been assumed that the shunt is applied at the A end of the track. The problem will now be considered with the shunt connected at the B end. The diagram in Fig. 3 shows the normal arrangement of the track circuit with the shunt connected at B and that in Fig. 4 shows the same track circuit and arrangement of conductors except that the track transformer has been transposed from the point T to the point R. From a general principle that applies to electric circuits it will be

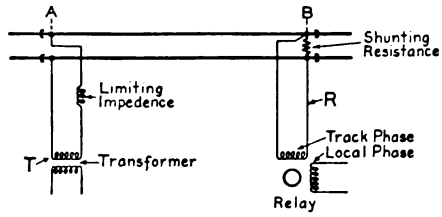

Fig. 3—Normal Arrangement of Track Circuit with Shunting Resistance Connected at B

understood that, with the same voltage at the transformer in both circuits, the current, considered as a complex quantity, in the track phase of the relay in Fig. 3 is the same as the current in Fig. 4 that flows through the limiting impedance.

With the circuit as in Fig. 4 in mind the general equation for shunting may be written:

$$G_s' = \frac{E\,Y'}{I_s'} - K'$$

The position angles for the A and B ends of the track for the circuit in Fig. 4 are determined from the equations:

$$\delta_A' = \tanh^{-1} Z_L\,/\,Z_0 \quad\text{and}\quad \delta_B' = \delta_A' + \theta$$

The position angles and the sinh, cosh and tanh of the angles have been computed and are as follows:

$$\delta_A' = 0.16038 + j\,1.2123$$
$$\delta_B' = 2.2898 + j\,1.7828$$
$$\sinh\delta_A' = 0.95016 \angle 86°.590$$

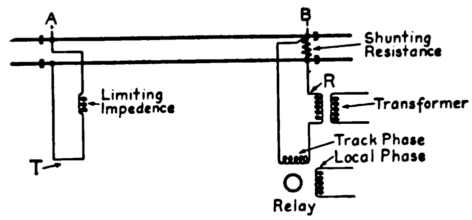

Fig. 4—Same Network of Conductors as Shown in Fig. 3 with Transformer Transposed from T to R

$$\sinh\delta_B' = 4.9828 \angle 101°.909$$
$$\cosh\delta_A' = 0.38610 \angle 22°.994$$
$$\cosh\delta_B' = 4.8904 \angle 102°.393$$
$$\tanh\delta_A' = 2.4609 \angle 63°.596$$
$$\tanh\delta_B' = 1.0189 \nwarrow 0°.484$$

The values of Y' and K' may now be expressed:

$$Y' = \frac{\cosh\delta_A'}{Z_B\,Z_0\sinh\delta_B'}$$

and

$$K' = \frac{Z_B + Z_0\tanh\delta_B'}{Z_B\,Z_0\tanh\delta_B'}$$

The value of K' may also be obtained from the relation:

$$K' = \frac{Y' K}{Y}$$

The values of Y' and K' as computed from these equations may be given as follows:

$$Y' = 0.09199 \;\overline{\diagdown}\; 141°.918$$
$$K' = 2.1680 \;\overline{\diagdown}\; 36°.235$$

The algebraic solution to determine G_s', I_s', the current in the track phase of the relay in Fig. 3, and ϕ_s' is the same as in the case where the shunt is connected to the rails at A, thus:

$$\frac{E\,y'}{i_d} \angle (\nu' - \beta) = 5.5996 \;\overline{\diagdown}\; 92°.419$$
$$= -0.23634 - j\,5.5946$$

whence, $m' = -0.23634$ and $n' = -5.5946$

$$-K' = -(2.1680 \;\overline{\diagdown}\; 36°.235) = -1.7486 + j\,1.2815$$

or $e' = -1.7486$ and $f' = 1.2815$

Then

$$G_s' = e' - n'/2 \pm \sqrt{(n'/2)^2 - m' f' - f'^2}$$

or $= 3.5953$

$$R_s' = 0.27814$$

$$\sin^2 \phi_s' = \frac{-n'(G_s' - e') - m' f'}{m'^2 + n'^2} = 0.96316$$

or $\sin \phi_s' = 0.98141$

and $\phi_s' = +78°.934$

Then $\gamma_s' = \beta - \phi_s' = \;\overline{\diagdown}\; 128°.434$

The size of the current I_s' equals

$$\frac{i_d}{\sin \phi_s'} = 0.11718 \text{ ampere}$$

The current I_s' in the track phase of the relay may then be written:

$$I_s' = 0.11718 \;\overline{\diagdown}\; 128°.434 \text{ ampere}$$

In what has been said previously in regard to the current in the relay it has been assumed that the maximum shunting resistance is connected across the track, and although this is important, it is also advisable to investigate the conditions when the shunting resistance is something other than the maximum resistance, as these are conditions that occur in practise.

The current in the track phase of the relay, when a variable conductance is applied as a shunt at A, may be expressed by the general equation in the form:

$$I_s = \frac{E\,Y}{K + G_s}$$

This equation may be readily solved graphically by a construction as shown in Fig. 5 in which the vector $K = 1.0088 \;\overline{\diagdown}\; 32°.665$ is first drawn to scale from the origin with reference to the rectangular coordinates. A line $o_1\,g$ of indefinite length is drawn horizontally to the right from o_1 to represent the conductance G_s. Any value of $K + G_s$ when G_s is variable, may be represented by a vector drawn from the origin so as to terminate in $o_1\,g$. With this thought in mind the line $o_1\,g$ may be taken to represent the admittance $K + G_s$. The line $o_1\,g$ is then drawn indefinitely to the left and is found to intersect o-Y at a point h. The circle S_4 which passes through the origin is drawn so that its diameter coincides with the negative ordinate o-Y and numerically equals the reciprocal of the distance $o\,h$. The circle S_5 is then drawn as the reflection of circle S_4 with reference to the horizontal axis. Circle S_5 represents all vector values of $\dfrac{1}{K + G_s}$. Since conductance has been assumed to be positive the negative values of G_s cannot exist physically. When G_s is confined to positive values the impedances represented by $\dfrac{1}{K + G_s}$ are vectors from the origin that

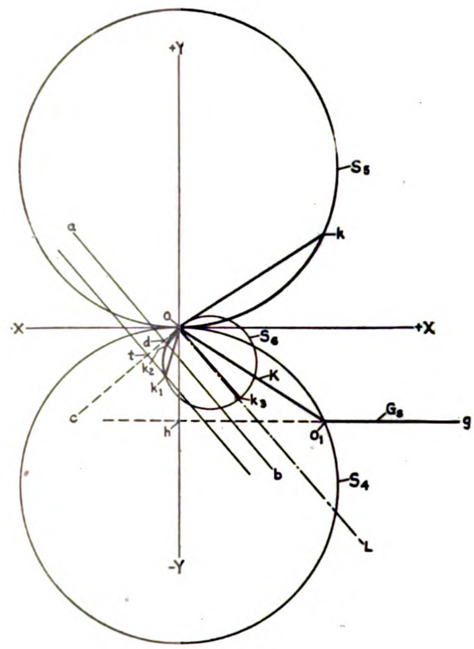

Fig. 5

terminate in the shorter arc of the circle S_5 between o and k. When G_s is zero the impedance $1/K$ is represented by vector $o\,k$ and as G_s increases to infinity the vector representing $\dfrac{1}{K + G_s}$ varies so that its terminus passes over the arc from k to o.

Operating on the circle S_5 by

$$E\,Y = 0.29965 \;\overline{\diagdown}\; 138°.349$$

changes the diameter in size by the factor 0.29965 and rotates the circle through an angle 138°.349 in a negative direction. This gives the circle S_6 which represents all vector values of $\dfrac{E\,Y}{K + G_s}$, but the only possible values of $I_s = \dfrac{E\,Y}{K + G_s}$ are those determined from G_s taken positively, and these are vectors that terminate in the shaded arc between k_1 and o. When $G_s = 0$ the vector $o\,k_1$ is the current in the track phase of the relay when the block is unoccupied. As the

conductance G_s is connected to the track and varied from zero to infinity the current I_s varies over the arc of the circle from k_1 to o. The angle between $o\,k_1$ and the diameter $o\,k_3$ of the circle S_6 is the same as the angle between vector K and the ordinate o-Y. Any other current value represented by a vector from o to the arc $o\,k_1$ is displaced from the diameter by the same angle that a corresponding vector from o to the line $o_1\,g$ is displaced from ordinate o-Y. The distance between o_1 and the terminus of this latter vector, $K + G_s$, represents the corresponding value of G_s.

For the purpose of comparing the phase displacement that exists between the currents in the track and local phase windings as G_s is varied the line $o\,L$ is drawn at $\angle\ \beta$ to indicate the slope of the local current. The angle between any value of I_s and the $o\,L$ indicates the phase displacement. The line $o\,c$ has been drawn at 90 deg. to $o\,L$ to show the current at 90 deg. phase displacement that will give equivalent operation of the relay by projecting any value of I_s on the line $o\,c$. The line $o\,d$ represents the drop-away current and the line $o\,t$ the current that gives normal operation of the relay. A circle S_6' might be drawn on the same diagram to show how the current in the relay varies when the shunt is connected to the rails at B. This circle is not shown because, in this particular case, the arcs of the two circles would nearly coincide.

In the practical adjustment of a track circuit it is usual to make the adjustment in wet weather when the ballast resistance is low; in any case, the adjustment must be such that there will always be sufficient voltage at the transformer to operate satisfactorily the relay. If as in the present case, the voltages is adjusted when the ballast resistance is low, then when the ballast dries out and the resistance increases there is an excessive current in the relay. The shunting then becomes poorer and the maximum shunting resistance is of course, less. In order to show the characteristics of the track circuit in regard to shunting under dry weather conditions, computations have been made on the assumption that the ballast resistance increases from 5 ohms to 20 ohms per 1000 ft. of track. The results of these computations are given in the table below, together with the numerical data obtained above, for comparison.

Data on Shunting or Relay in 9000-Ft. Track Circuit
$E = 7 \angle 0°$ Volts $Z_l = 3 \angle 80°$ Ohms $Z_R = 0.64 \angle 53°$ Ohm

Ballast Resistance	Track Section Unoccupied	Track Section Shunted at A	Track Section Shunted at B
5 ohms	$I_B = 0.29703 \overline{\backslash}\, 105°.684$	$I_s = 0.11830 \overline{\backslash}\, 125°.936$	$I'_s = 0.11718 \overline{\backslash}\, 128°.434$
•	$\phi = +56°.184$	$\phi_s = +76°.436$	$\phi'_s = +78'.934$
•	$\sin\phi = 0.83083$	$\sin\phi_s = 0.97211$	$\sin\phi'_s = 0.98141$
•	$i = 0.24678$	$G_s = 1.6245$	$G'_s = 3.5953$
•		$R_s = 0.61556$	$R'_s = 0.27814$
20 ohms	$I_B = 0.79965 \overline{\backslash}\, 74'.983$	$I_s = 0.12747 \overline{\backslash}\, 113'.948$	$I'_s = 0.13050 \overline{\backslash}\, 111°.288$
•	$\phi = +25°.483$	$\phi_s = +64°.448$	$\phi'_s = +61°.788$
•	$\sin\phi = 0.43024$	$\sin\phi_s = 0.90219$	$\sin\phi'_s = 0.88121$
•	$i = 0.34404$	$G_s = 3.8051$	$G'_s = 9.5770$
•		$R_s = 0.26281$	$R_s = 0.10442$

In referring to the table it will be seen that with the block unoccupied the current in the track phase increases in a ratio approximately 2.7:1 as between wet and dry weather conditions. This is not as bad as it would appear because the phase displacement becomes less. The equivalent current i at 90 deg. phase only increases in the ratio 1.4:1 as the ballast dries out. The application of a resistive shunt at the track increases the lag in phase of the current and gives a larger phase displacement. The phase displacement ϕ_s is not as unfavorable in dry weather as is evident by a comparison of the values of $\sin\phi_s$. It will be seen from the values of R_s that the shunting is not as good at the relay end of the track as it is at the transformer end.

Throughout the discussion it has been assumed that the shunting of the relay is accomplished by connecting a resistance across the track and this is the condition when the shunting is effected through contacts in a switch box, which is one of the most difficult conditions to meet. However, it has been claimed that the shunt through the wheels and axles of a train is somewhat inductive, but no reliable data appear to be obtainable as to the power factor of a train shunt. It can be shown in the present case that the relay will release its contacts more readily with an impedance shunt. For instance, in Fig. 2 the dotted line $o_1\,g_2$ which represents the admittance corresponding to a shunting impedance, is less than $o_1\,g_1$ the minimum conductance G_s. This is not always the case. It can be shown in a similar manner under some conditions that it becomes more difficult to shunt the relay with impedance than with resistance.

It may be well to refer to the importance of drawing the diagram in Fig. 5. In this case the current circle S_6 shows that the relay shunts as it is intended to do when a resistance is connected across the rails. There may be instances where the track circuit is poorly adjusted or where abnormal conditions arise such as high rail resistances due to broken bond wires, and when such conditions exist an excessive voltage may be applied to the track in an attempt to operate the relay. Under some of these unusual conditions when a fairly high resistance is connected across the rails the torque at the rotor shaft may increase instead of decreasing to allow the relay to release its contacts. Again, in three-position signaling when a shunt is connected it may happen that the relay instead of simply releasing its contacts will tend to pick up to close the contacts in a reverse direction. In investigating such conditions the current circle S_6 will be useful in determining the performance of the relay.

JOURNAL OF THE American Institute of Electrical Engineers

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

A. I. E. E. MIDWINTER CONVENTION
FEBRUARY 15-17, 1922

The 10th Midwinter Convention of the Institute will be held in New York, February 15-17, 1922, in the Engineering Societies Building. This will be the first meeting in 1922 under the new policy adopted by the Board of Directors which prescribes four general meetings of the Institute each year including the annual convention.

The Meetings and Papers Committee has in hand several papers which have been accepted, and is prepared to consider for this program any further manuscripts which may be received prior to December 15th. The complete program will be printed in the January JOURNAL.

NEW YORK SECTION MEETING CANCELLED

December 14 meeting. Because of a conflict of dates it has been necessary to cancel the joint meeting of the N. Y. Section of the Institute and the Metropolitan Section of the A. S. M. E. on "Central Station Operating" scheduled for December 14. It is also believed this cancellation will permit members to devote more time to the many outside affairs demanding attention at that season of the year.

FUTURE SECTION MEETINGS

Atlanta.—December 29, 1921. Subject: "Muscle Shoals" (illustrated). Speaker: Mr. C. G. Adsit, Chief Consulting Engineer. Georgia Railway & Power Co.

Baltimore.—December 8, 1921. Paper: "Design and Construction of the Westport Generating Station." Speaker: Mr. A. S. Loizeaux, E. E., Consolidated Gas & Electric Light & Power Co. Paper: "Operating Problems in the Westport Generating Station." Speaker: Mr. Abbott L. Penniman, Supt. of Steam Stations, Consolidated Gas, Electric Light & Power Co. The meeting will be held in the Service Building at the Westport Generating Station and will be followed by an inspection tr p through the station.

January 20, 1921. Paper: "The Use of Electricity for Industrial Heating." Speaker: Mr. C. F. Hirshfield, Chief of Research Department, Detroit Edison Company.

Connecticut.—December 15, 1921, Auditorium of Hartford Electric Light Company, 266 Pearl Street, Hartford. Subject: "Caribou Hydroelectric Development of the Great Western Power Company, California." Speaker: Mr. Albert A. Northrop, of the Stone & Webster Engineering Corporation, Boston.

Chicago.—December 16, 1921, Rooms of the Western Society of Engineers, 330 South Dearborn Street. Joint meeting with the Western Society of Engineers and the Association of Iron and Steel Electrical Engineers. Subject: "Application of Electric Power to Iron and Steel Industry." Speaker: W. S. Hall, E. E., South Works of the Illinois Steel Company.

Kansas City.—December 18, 1921. Telephone meeting.

Lehigh Valley.—January 12, 1921, at Bethlehem, Pa. Subject: "Electricity Aboard Ship."

Toronto.—December 9, 1921. Room 22, Chemistry and Mining Building, Toronto University. Subject: "Distribution Records and Overhead Distribution." Speaker: Mr. C. E. Schwenger, of the Toronto Hydroelectric System.

A. I. E. E. MEETING IN NEW YORK
NOVEMBER 17, 1921

The Joint Meeting of the Society of Naval Architects and Marine Engineers and the American Institute of Electrical Engineers was held at the Engineering Societies Building, on Thursday afternoon, Nov. 17, 1921. The meeting was called to order by President McClellan, of the Institute, who presided during the first half, and Admiral Capps of the Society of Naval Architects and Marine Engineers presided during the second half.

The following papers were presented:

"Electric Propulsion of Ships," by Mr. W. E. Thau, Member, A. I. E. E., Marine Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

"Electric Auxiliaries on Merchant Ships," by Mr. E. D. Dickinson, Member, S. N. A. & M. E.; Associate, A. I. E. E., Mechanical Engineer, Marine Department, General Electric Co., Schenectady, N. Y.

These were discussed by W. L. R. Emmet, Charles F. Bailey, William Walker Smith, Capt. Q. B. Newman; Elmer A. Sperry; E. H. B. Anderson; Frederick C. Bates; G. H. Jett; G. A. Pierce; communicated discussion by Charles Rettie, of Liverpool, England; E. A. Stevens, Jr., W. McClelland, Director of Electrical Engineering, British Admiralty; Commander S. M. Robinson; H. L. Hibbard; Rear Admiral John K. Robison, Chief Engineer, U. S. Navy, followed by closure by the authors.

At the evening session an illustrated lecture on World Communication was given by Dr. Alfred N. Goldsmith, in which he traced the growth of the communication systems of the world by ocean cables, land lines and wireless. Moving pictures were shown of ocean cable laying, the operating machinery and apparatus of important stations and some of the largest and latest wireless equipments.

INSTITUTE PRIZES

At the meeting of the Board of Directors of the Institute of April 16, 1921, recommendations were approved establishing two Institute prizes to be awarded yearly to authors of worthy

papers. The following extracts from the report of the Committee on Coordination of Institute Activities embody the essential features of the procedure to be followed as outlined by them. Members of the Institute are reminded that January 15, 1921 is the last date for submitting to the Secretary papers that are to be considered in competition for the 1921 awards.

THE FIRST PAPER PRIZE

(1) This prize, established by the Board of Directors of the Institute, January 14, 1921, shall consist of $100 cash, and a suitable certificate, to be awarded each year to the author of the paper which is designated by a duly authorized committee of award as the most worthy original paper, presented during the year at a meeting of any Section of the Institute; by a member of the Institute who has never before presented a paper before the Institute or any of its Sections.

(2) To be considered for competition, the author, or an officer of the Section at which the author's paper was presented, shall submit the paper to the committee of award, by means of a written communication to the Secretary of the Institute, prior to January 15 of the year following the calendar year in which the paper was presented.

(3) Papers by joint authors are eligible for this competition, provided both authors meet the qualifications, in which case the prize shall be divided equally between the authors.

(4) The award shall be made by a committee consisting of the Chairman of the Meetings and Papers Committee as chairman, and the chairmen of the technical committes of the Institute, prior to June 1.

(5) The prize shall be presented at the Annual Convention of the Institute.

(6) The paper shall be published in the monthly JOURNAL or annual TRANSACTIONS of the Institute, or both.

(7) Manuscripts shall be submitted in duplicate and shall be typewritten on one side of paper of approximately 8½ by 11 inches. The letter entering the paper in the competition need not be accompanied by duplicate copies of the paper, provided suitable manuscript copies in duplicate have been submitted previously.

THE TRANSMISSION PRIZE

(1) This prize, established by the Board of Directors January 14, 1921, shall consist of $100, and a suitable certificate, to be awarded each year to the author of the paper which is designated by a duly authorized committee of award as the most worthy paper dealing with the art of transmitting electrical energy over considerable distances, presented during the year by a member of the Institute, at a meeting of the Institute or of any of its Sections.

(2) To be considered for competition, the author shall submit the paper to the committee of award, by means of a written communication to the Secretary of the Institute, prior to January 15 of the year following the calendar year in which the paper was presented.

Paragraphs three to seven as printed above under the heading "The First Paper Prize," also apply to this award.

A. I. E. E. TRANSACTIONS

An important change in the policy to be followed in the distribution of the annual TRANSACTIONS of the Institute has been adopted, as explained in a notice issued to all members of the Institute under date of November 12.

The volume covering the year 1920, publication of which has necessarily been delayed for financial reasons, is now completed and will be forwarded to all members entitled to receive a copy, during the month of December 1921.

The new policy takes effect with the volume covering the year 1921 in accordance with the following resolution which was considered and approved by the Board of Directors at a meeting in October 1920:

VOTED, that commencing with the volume of Institute TRANSACTIONS covering the year 1921, the practise of furnishing a copy of the TRANSACTIONS to each member of the Institute be discontinued, and that copies be furnished to all members who subscribe in advance at a price to be determined later, possibly $5 per year; the edition to be determined by the advance subscriptions received, with a reasonable allowance for stock to meet future demands.

The immediate occasion of the above action was the condition of the Institute's finances, caused by continuing all the activities of the Institute, at prevailing increased costs, without increasing the annual dues. The action was adopted after learning, through the Development Committee and through conference with the representatives of the various Sections at recent annual conventions, the attitude of the membership regarding the publications of the Institute.

The greatly increased cost of publishing the JOURNAL and TRANSACTIONS, together with the increased amount of suitable material available for publication, has rendered it necessary that the policy outlined above be now put into effect, and the following plan has been decided upon by the Board of Directors in connection with the 1921 and 1922 TRANSACTIONS.

1921 Transactions. This volume of the TRANSACTIONS is about to go to press, and the edition will be determined by the number of subscriptions received by January 1st, 1922, in response to the circular mailed to the membership November 12. The price of the TRANSACTIONS will be $3.00 *to the membership only.* (The regular price to non-members will still apply.)

1922 Transactions. Commencing with this volume, it has been decided to print each month in conjunction with the printing of the JOURNAL additional pages to be reserved and bound at the end of the year to form the volume of the TRANSACTIONS for those members who desire a file of papers and discussions in this form. The practise of printing discussions in the JOURNAL will be reestablished. The material to be contained in the TRANSACTIONS will be selected exactly as heretofore, the only difference in the volume being in the size of the pages, as pages from the JOURNAL will become identical with pages in the TRANSACTIONS, with the exception of a required change in folio numbers.

The edition of the TRANSACTIONS for 1922 will be based upon the number of members who make application therefor by January 1st, 1922, at the nominal price of $2.00 per year *to the membership only.*

The adoption of the above policy, resulting in the saving of a large portion of the expense caused by duplication of printing, will permit of the publication of additional desirable material, particularly relating to the activities of the Sections, and the further development of the JOURNAL in accordance with the policy decided upon in the fall of 1919, in response to the expressed wishes of the membership.

Each member who desires a bound copy of either the 1921 or 1922 TRANSACTIONS or both, is urged to make prompt application therefor, as only a limited number of surplus copies will be printed.

NOMINATION AND ELECTION OF INSTITUTE OFFICERS FOR 1922-1923

As provided in Section 19 of the Institute By-Laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1922, by the petition or by the separate endorsement in writing, of not less than twenty-five members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1922. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: A President and a Treasurer for the term of one year each, five Vice-Presidents for the term of two years each (one from each of the odd numbered geographical districts), and three Managers for the term of four years each.

The five odd numbered districts from which Vice-Presidents are to be chosen at the May 1922 election are as follows:

1. North Eastern: Connecticut, Maine, Massachusetts, New Hampshire, New York (exclusive of N. Y. Section territory), Rhode Island, Vermont.

3. New York City: Territory of the New York Section, Canal Zone, Porto Rico, all foreign countries (Canada excepted).

5. Great Lakes: Illinois, Indiana, Michigan, Wisconsin.

7. South West: Arkansas, Kansas, Missouri, New Mexico, Oklahoma, Texas.

9. North West: Idaho, Montana, Oregon, Utah, Washington, Alaska.

According to the revised Constitution, while one Vice-President must be elected from each of the five odd numbered districts, this does not debar members in one district, if they so wish, from nominating and voting for a candidate in another district. When the votes are counted the candidate for Vice-President having the largest vote in each district will be elected to that particular office for that district, irrespective of the fact that he may have polled a smaller number of votes than a candidate standing second in another district.

For the information of members the full text of revised sections of the Constitution and By-Laws applying to Officers, nominations, elections, etc., are printed below:

CONSTITUTION

SEC. 23. The officers of the INSTITUTE shall be a President, one Vice-President from each geographical district as defined in the By-Laws, twelve Managers, a Secretary and a Treasurer.

SEC. 24. The President, the Secretary and the Treasurer shall hold office for one year, the Vice-Presidents for two years and the Managers for four years. The President and Managers shall not be eligible for immediate re-election to the same office. No Vice-President or Manager who has served continuously in one or more offices, and whose combined terms shall have aggregated six years or more shall be eligible for immediate election to the office of Manager or Vice-President. At each Annual Meeting the President, the requisite number of Vice-Presidents to fill vacancies caused by expiration of terms, three Managers and the Treasurer shall be elected by the membership, and their terms of office shall commence on the first of August next succeeding their election.................

SEC. 24A. At the election of Vice-Presidents held in 1921 there shall be elected one Vice-President from each geographical district, those from the odd-numbered districts to serve for one year each, and those from the even-numbered districts two years each. All Vice-Presidents elected thereafter shall serve for two years each. In the event of a change in the geographical districts, the Vice-Presidents then in office shall complete their terms. In case of revisions of the geographical districts, the Board of Directors shall have the power to elect a Vice-President from each district not represented, to serve until the next election covering these districts.

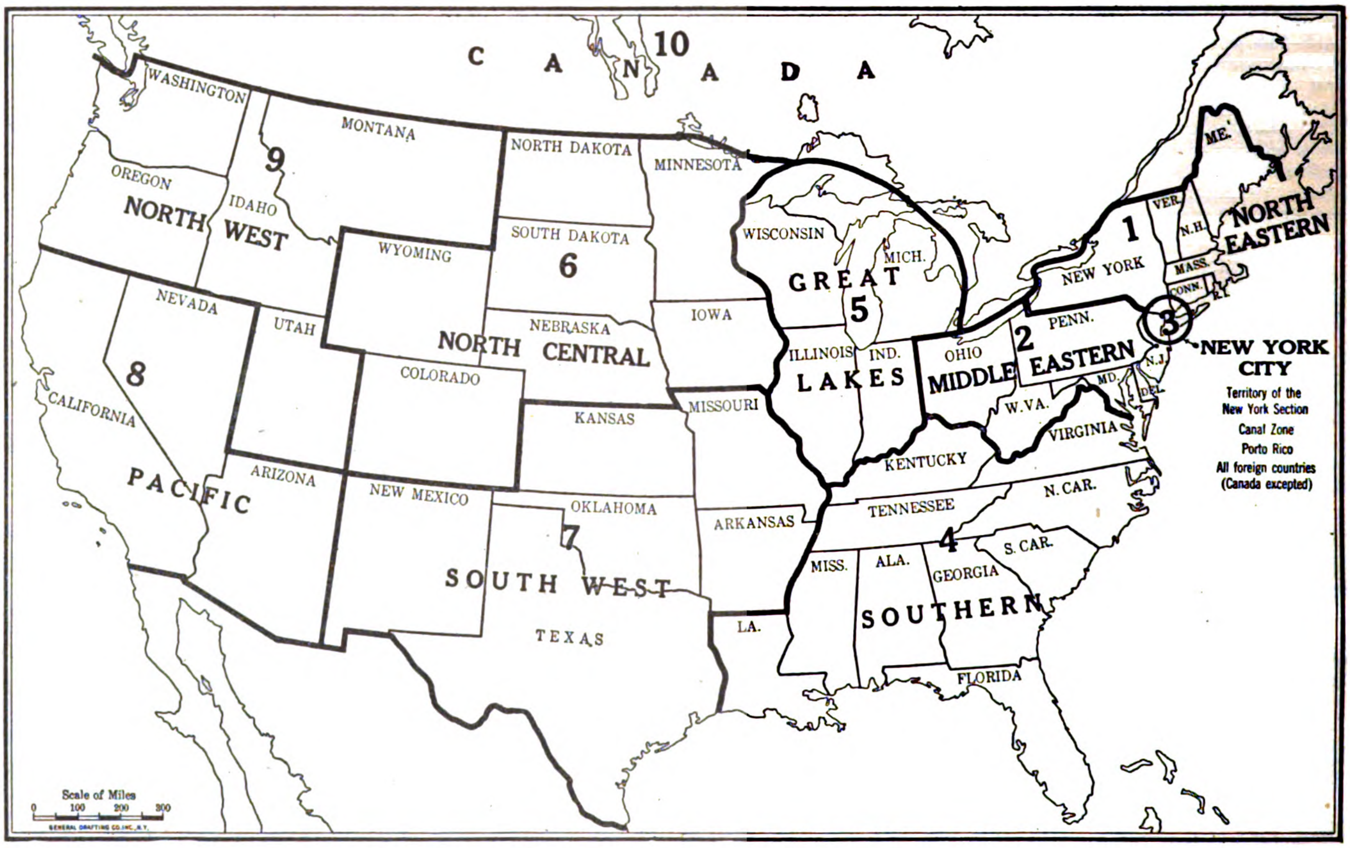
BY-LAWS

SEC. 19. In addition to the names of the incumbents of office the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May provided for in Article VI, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than twenty-five members, received by the Secretary of the Institute in writing by January twenty-fifth of each year; provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's JOURNAL and shall be reproduced on the form above referred to.

SEC. 21. There shall be ten geographical districts grouped as follows: (For the balance of this Section describing districts see paragraph preceding map.)

SEC. 21A. Should the territory of any Institute Section lie in more than one geographical district as defined above, then the entire territory of said Section shall be considered as belonging to the geographical district in which the headquarters of the Section are located.



Geographical districts into which the membership of A. I. E. E. has been divided for the purpose of electing Vice Presidents.

DR. J. B. WHITEHEAD AWARDED THE MONTEFIORE PRIZE

A triennial prize of 5000 francs given by the Foundation George Montefiore, Liege, Belgium, has been awarded to Dr. John B. Whitehead, Professor of Electrical Engineering, The Johns Hopkins University, Baltimore Md., for his research work in connection with a paper on "The Corona Voltmeter and the Electric Strength of Air," written by him in collaboration with a graduate student, T. Isshiki, and presented before the A. I. E. E. at the White Sulphur Springs Convention, June 1920. The prize is awarded by a jury of ten electrical engineers, of whom five are Belgian and five from other countries, for the best original work on scientific advancement or progress in the technical applications of electricity in all its branches.

AMERICAN ENGINEERING COUNCIL

NEXT MEETING OF COUNCIL IN WASHINGTON, JANUARY 5-6

The next meeting of the American Engineering Council of the Federated American Engineering Societies will be held in Washington, January 5 and 6. The date was determined at a meeting in New York City of the Council's Committee on Procedure, consisting of Calvert W. Townley, J. Parke Channing, Dexter S. Kimball, William McClellan and W. E. Rolfe. The meeting was attended by Dean Mortimer E. Cooley, the new president of the Council, who spent several days in New York familiarizing himself more intimately with national engineering policies and with L. W. Wallace, executive secretary of the Council, and members of the Committee on Procedure, working out details of Federation organization and development.

LAMPERT PATENT OFFICE BILL

In urging the passage of the Lampert Patent Office Bill, H. R. 7077, as announced in the November issue of the JOURNAL in the report of the September meeting of the Executive Board, American Engineering Council requests the support of the individual members of the Federated American Engineering Societies. Each member of the societies belonging to the Federated American Engineering Societies is requested to communicate with his Senator and personal Representative, urging the immediate enactment of the Lampert Patent Office Bill.

The report of the Committee on Patents, approved by the Executive Board at the September meeting, contained the following resolutions regarding this bill:

WHEREAS, American Engineering Council, of The Federated American Engineering Societies, representing 43,000 engineers in member and affiliated societies, is strongly convinced of the importance of the Patent Office to the maintenance of the manufacturing and agricultural welfare and supremacy of the United States and is deeply concerned over the present precarious and inefficient condition of the Patent Office, the said American Engineering Council represents to Congress that, while the Patent Office was in a most serious condition in 1919, when the need of its relief was first brought to the attention of Congress, the work of the Patent Office has increased 67.6 per cent, since that time, while the Patent Office force has only been increased 5.4 per cent, the salaries of examiners remaining at but 10 per cent more than they were in 1848, and the resignations of the Patent Office examiners have continued in increasing volume until but one-half of the examining force now consists of properly trained examiners; and

WHEREAS, the Lampert Patent Office Bill, H. R. 7077, provides the least increases in force and salaries which can possibly stop the retrogression of the Ptatent Office and enable it to make progress toward recovering an efficient condition, and by increases in the fees for patents, provides the funds necessary to enable the Patent Office to continue to be self-supporting;

NOW THEREFORE, AMERICAN ENGINEERING COUNCIL most urgently recommends to Congress the passage of the said Lampert Patent Office Bill, H. R. 7077.

The Patent Office has for years suffered from lack of proper support and as a result, American industry and commerce have been seriously retarded. The earnest support of the individual members of the Federated American Engineering Societies will materially aid in bringing about the passage of the Lampert Patent Office Bill which will enable the Patent Office to render the service demanded.

ELIMINATING WASTE IN ESTIMATING

A document on "Eliminating Waste in Estimating" has been produced through the cooperated work of the American Institute of Architects, The Associated General Contractors of America and the American Engineering Council. The report will prove of value to those interested in building and other construction projects, containing especially information to interest owners and investors, architects and engineers, and contractors. Anyone desiring a copy of this document may obtain one without charge upon application to The Federated American Engineering Societies, 719 Fifteenth St., N. W., Washington, D. C.

COMMITTEE ON ENGINEERING EDUCATION APPOINTED

One of the most important acts of the Committee on Procedure at its recent meeting was the appointment of a committee to work out a policy of engineering education. Col. A. S. Dwight of New York, Prof. Charles F. Scott of Yale and William W. Varney of Baltimore were appointed as members of this committee.

The committee was named as a result of a vote of the Executive Board "to appoint a Committee on Engineering Education to report what attitude the Federated American Engineering Societies should take."

The Board's decision to take up thoroughly the whole question of engineering education followed a discussion engendered by a resolution of Mr. Varney stating that "there is a feeling among engineers of this country that the engineering colleges have not expanded to meeting the present day demands in the most satisfactory manner." The resolution asked that the Federation appoint "a Committee on Education to consider broadly the training of the engineer and to report on desirable changes in present day engineering education to better prepare engineering graduates to take their proper places in the profession."

The University of Iowa has addressed a communication to the Executive Board recommending "that it is desirable to make an effort to have the American Engineering Council of the Federated American Engineering Societies establish standards of engineering education for engineering colleges of different grades and to rate the engineering colleges of the country in accordance with the classification adopted," and suggesting the establishment of five-year engineering courses, the first year of which should be given in the College of Liberal Arts and no specialization made except in the course in Chemical Engineering until the fifth year, the establishment of such five-year course being considered as a preliminary step toward the establishment of six-year courses.

Another communication to the Board on this subject was in the form of a paper on "The Status of Engineering Education" by Prof. John H. Dunlap, president of the Iowa Engineering Society.

The general consensus of opinion among the members of the Board was that there was a number of other organizations more directly affected by and concerned with these matters, that were giving consideration to them, and hence, it was not within the purview of the Federation to take them up. But since the subject had been broached and since written communication had been received suggesting that the Federation should be active in such things, it was decided to institute appropriate inquiry through a special committee.

Col. Dwight, Prof. Scott, and Mr. Varney are all members of the Executive Board and have taken a deep interest in engineering education policies.

PERSONAL MENTION

JOEL S. LAWSON recently left R. Thomas & Sons Company of New York to become general manager of the Memco Engineering & Mfg. Company, Inc., New York.

JOHN H. EBAUGH has left the Allis-Chalmers Manufacturing Company of Los Angeles to become instructor in the electrical department of the Fresno Technical High School, Fresno, Cal.

CHAS. H. MATTHEWS is with the Smith Green Company of Worcester, Mass., as sales engineer. He was until recently an electrical engineer with the Westinghouse Electric & Mfg. Company.

HOWARD W. THOMAS has left Washington D. C., to become inspector of electrical material in the Plant Department of the Boston Navy Yard.

ROBERT H. HULL has become instructor of electrical engineering in the University of Colorado, Boulder, Colo. He was previously with the Great Western Sugar Company, of Denver.

PERRY L. HARRIS has left the Federal Shipbuilding Company, Kearny, N. J., to become connected with the Newberry Electric Corporation of Los Angeles, Cal.

C. F. SCHOONMAKER, who was assistant engineer with the Quaker Oats Company, Chicago, is now with The Iowa Railway & Light Company, Cedar Rapids, Iowa.

CHAS. H. YOST, formerly with the General Electric Company, has become located with the Niagara, Lockport, and Ontario Power Company, Buffalo, N. Y.

JAMES DEALEY has severed his connections with the Crescent Pure Milk Company of Winnipeg, Man., and is located with the Central Repair Company of that city.

HERMAN W. BOCHER has left his work as instructor of electrical engineering in the School of Engineering, Milwaukee, to become power dispatcher with the Illinois Traction System, Peoria, Ill.

CHAS O. GIBBON, formerly research engineer with the Fessenden Engineering Laboratory, Boston, has become connected with the American Telephone & Telegraph Company, New York, as assistant engineer.

CARL H. DUNLAP has become head of the electrical engineering department of the American School of Correspondence, Chicago, having left his position as chief inspector with Roth Brothers & Company, of Chicago.

DENIS V. PAFINEAU has accepted a position in the method engineering department of the Western Electric Company, Inc., New York. He was previously a telephone engineer with the Northern Electric Company, Ltd., Montreal.

ERNEST R. FELLOWS, who was with the General Electric Company as inspector of hull material for the U. S. Navy, has left Schenectady to become superintendent of construction for the Associated Telephone Company, Long Beach, Cal.

F. T. COUP has been appointed district manager of the Cincinnati office of the Wagner Electric Manufacturing Company. He has been connected with the Wagner Company for a number of years, being formerly in charge of the Milwaukee office.

ALEX J. LARDNER, formerly electrical inspector with the Public Works Department of New Zealand, has become managing director of The Union Electrical Company, Ltd., Timaru, N. Z.

GEO. LEE HOADLEY is now head of the department of electricity in the School of Engineering, Milwaukee, Wis. Until this fall he was teaching in Washington State College at Pullman, Wash.

H. P. SPARKES, formerly with the Westinghouse Electric & Manufacturing Company, E. Pittsburgh, has become located in the meter department of the West Penn Power Company, Pittsburgh.

T. W. CARRAWAY has resigned his position with the government as chief engineer, U. S. Government Repair Unit No. 304, to go into business, forming the Carraway Engineering Company of San Antonio, Tex., specializing on mechanical refrigeration.

WM. HOWARD GROVE, formerly with the Republic Railway & Light Company, New York, has entered the electrical engineering department of the Cleveland Electric Illuminating Company of Cleveland, Ohio.

ARTHUR C. STANSFIELD, of the Commonwealth Edison Company, Chicago, is in England on a six months' vacation. He expects to return to the United States or Canada next spring. His present address is No. 24 Ashley Lane, Moston, Manchester, Eng.

OSWALD DALE has accepted the position of general manager of the Pittsburgh Insulating Company, Pittsburgh, Pa. Until recently he was connected with the Irvington Varnish & Insulator Company, Irvington, N. J., as vice-president and general manager.

G. W. SOENGEN of G. W. Soengen & Company, St. Louis, a company recently organized by him, has purchased the entire survey notes and records of both B. E. Johnson and Jos. W. Wilson, surveyors and civil engineers of St. Louis County, Mo. The company will carry on electrical, civil, and mining engineering.

F. T. WRIGHT, who recently resigned his position as assistant chief mechanical engineer of the Royal Siamese State Railways, has been appointed chief electrical engineer of the Bombay, Baroda and Central India Railway Company with headquarters in Bombay. The company proposes to electrify the Bombay suburban lines.

A. W. BATES has been appointed stores manager of the Western Electric Company at Detroit. Mr. Bates has been connected with the company for twelve years, entering the telephone department at New York, where eventually he became head of the service department. In 1918 he was sent to New Haven as manager.

EMERSON A. ARMSTRONG is now located with the Public Service Company of Northern Illinois, in charge of power sales for the Joliet district. Mr. Armstrong some months ago left the Lincoln Motor Company, of Detroit, where he was assistant superintendent of construction and maintenance, and has since been engaged in special design and lecture work at the Michigan State College.

WM. A. WINTER, who has been in Europe to obtain information regarding X-ray cancer treatment, returned recently and will start in business for himself. Mr. Winter has been connected with the Kny-Scheerer Corporation of America, New York City, for thirty years, devoting his full time since 1895 to the development of X-ray apparatus. He joined the Institute during the past year.

HAROLD B. FISK was recently appointed manager of the Walsh Plate & Structural Works, Ltd., at Drummondville, Que. Mr. Fisk has seen service with several large Canadian power companies since coming to Canada from England in 1907, having been previous to his present appointment superintendent of the Drummondville Division of the Southern Canada Power Company. He became a member of the Institute in 1919.

A. W. K. BILLINGS has returned from Barcelona, Spain, to act as construction manager for the English and Canadian interests controlling large public utility companies in Mexico, Brazil and Spain, and as vice-president of the Canadian Engineering Agency, Inc., New York City. During the war Mr. Billings was in charge in Europe of naval aviation construction work ashore. He was promoted to the rank of Commander in the Naval Reserve and was awarded the Navy Cross and the Legion of Honor.

EDWARD M. ELIOT has been appointed assistant to the vice-president of the Underfeed Stoker Company of America, having resigned as service manager for the Diamond Power Specialty Company of Detroit. Mr. Eliot was engaged in power plant design and construction for eight years with the Oregon Electric Railway Company, The Electric Bond & Share Company, and others; and for the past seven years he has specialized in the organization of service work and repair sales. He is a graduate of Massachusetts Institute of Technology.

ARTHUR LUCIAN WALKER, professor of metallurgy in the School of Mines, Engineering and Chemistry of Columbia University, has been elected a member of the Board of Engineering Foundation. He succeeds the late Dr. Joseph W. Richards, representing the American Institute of Mining and Metallurgical Engineers on the Board. Prof. Walker is internationally known as an inventor and a teacher. One of his inventions was a mechanical casting machine which revolutionized methods used for casting copper into refined shapes, and another was a new system for electrolytic copper refining tank room arrangement, which has been largely installed in copper refining plants built since the invention in 1902.

OBITUARY

ROBERT MCKAY, barrister at law and member of the firm of McKay, Dods and Grant, Toronto, Ontario, died of throat trouble on November 6th at the Wellesley Hospital after an illness of less than a week. Mr. McKay was a graduate of the Toronto Collegiate Institute and the University of Toronto. He was called to the bar in 1891 and has been connected as counsel with many prominent railroad and hydroelectric litigations and inquiries. He joined the Institute in 1904.

WARREN H. FISKE, a Fellow of the Institute, died September 8, 1921, of acute appendicitis. Mr. Fiske had made his home in Marblehead, Mass., for the past year and a half. His engineering experience was largely in the field of steam and hydraulic power plants, including seven years as electrical engineer with the Metropolitan Street Railway, New York City; four years as resident engineer in Toronto connected with the Niagara Falls power substations and the steam plants in Toronto and Winnipeg, Man.; six years as chief engineer of the Mexican Light and Power Company and Mexico Tramway Company at Mexico City; and two years as general superintendent of the Barcelona Traction Light & Power Company in Spain. Previous to the war he was engaged in work at the Ammonia Nitrate Plant at Muscle Shoals, Ala., and during the war was in government service at Boston, in the Bureau of Aircraft Production of the War Department. Mr. Fiske was born in Somerville Mass., in 1869, and was a graduate of Tufts College, 1891.

LEON H. SCHERCK died at his home in Poughkeepsie, N. Y., on November 16, 1921. Mr. Scherck was born in New Orleans, La., in 1875, receiving his education at Tulane University, from which he received the degree of Mechanical Engineer in 1896. He started to work with the Louisana Electric Light Company, which was afterwards absorbed by other companies. In 1903 he left New Orleans for New York, later becoming connected with the Central Hudson Gas & Electric Company of Poughkeepsie, with which he remained until the time of his death. Mr. Scherck joined the Institute in 1906.

RAYNOR M. BEDELL, of Montclair, N. J. died on November 5, 1921, of tetanus, developing from a cut by glass on his foot three weeks previous. Mr. Bedell had been associated with the later Peter Cooper Hewitt as electrical expert. He was born in Montclair in 1880, and was graduated from Cornell University in 1902, joining the Institute the following year. He is survived by a brother Prof. Frederick Bedell of Cornell a former vice-president of the Institute.

JAMES HOWARD BECKER, formerly assistant instructor in the electrical engineering laboratory of the Massachusetts Institute of Technology, died suddenly on October 22 at Oberlin. Mr. Becker, just 24 years old, had been a student at the Massachusetts Institute of Technology for the past six years, continuing his studies there while a member of the faculty. He had recently accepted a position, however, with the Sandusky Foundry & Machine Company. His death occurred while he was on his way to a football game; apparently fainting, he could not be revived. He was buried in Clyde, Ohio, his birthplace.

CHARLES R. CROSS, professor emeritus of physics of the Massachusetts Institute of Technology and a charter member of the A. I. E. E., died November 16 at his home in Brookline, Mass. Prof. Cross was born in Troy, N. Y., in 1848, and was graduated from the Massachusetts Institute of Technology in 1870. The next year he became an assistant in physics in that institute, with which he has been connected ever since, being appointed professor of physics, then director of the Rogers Laboratory, and finally retiring a few years ago with the title of professor emeritus. It was largely due to his foresight and recognition of the increasing importance of electricity in modern life that the Massachusetts Institute of Technology offered the first degree given in an electrical engineering course in the United States. As a teacher Prof. Cross held to the highest standards of student training. He was an authority on sound, and aided greatly in the development of the telephone. Many contributions from him have been published, including the article on "Telephony" in the Encyclopedia Britannica. Besides being a member of the A. I. E. E. since 1884, Prof. Cross was a fellow of the American Academy of Arts and Sciences, a member of the American Physical Society, British Association for the Advancement of Science, and past-chairman of the American Association for the Advancement of Science and of the Rumford Fund Committee.

ALFRED ROLAND VAN HORN died on October 25 after a protracted illness of nearly two years. Mr. Van Horn was an inventor of electrical appliances, one of which was an automatic

control for isolated power plants. He was engaged in the manufacture of this machine with the Trumbell Electric Manufacturing Company of Plainville, Conn., until his illness caused him to stop active work. Born in Philadelphia in 1886, Mr. Van Horn attended the Pennsylvania State College and Drexel Institute for two years each. After three years of engineering experience in a partnership, he started his experimental work in 1911, and continued in that line, becoming in 1919 an engineer with the Trumbell Company, which had bought the manufacturing right to his device. During the war ill health kept Mr. Van Horn from passing the physical examination for the army, but he did construction work at the Hog Island navy yard and also at one of the stations of the Philadelphia Electric Company. He joined the Institute early in 1920.

WILLIAM EDGAR BAKER died suddenly of heart disease at 50 East 58th Street, New York City, on November 7, 1921. Prominent in both the civil and electrical engineering fields, Mr. Baker had retired from active business in recent years. He was born at Springfield, Mass., in 1857, and was graduated from Lafayette College in 1877. He then entered the service of the Canadian Pacific Railroad under such conditions of hardship that few survived, but soon showed his ability. In 1884 he left this to become resident engineer for the International & Great Northern Railway, in Texas. Four years later he began his career as electrical engineer, accepting appointment as superintendent in charge of the installation of electricity on the West End Street Railway System of Boston. From 1892-94 he designed and built the Columbian Intramural Railway in Chicago, a work which brought him into prominence both in this country and in Europe. During the next five years he was general manager and chief electrical engineer of the Metropolitan West Side Elevated Railroad in Chicago. In 1899 he came to New York to accept the same position with the Manhattan Elevated Railroad, operating the railroad as its general manager until he resigned and opened an office in New York as consulting engineer. He was a trustee of Lafayette College, and deeply interested in its welfare. He joined the Institute in 1901.

ENGINEERING SOCIETIES LIBRARY

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (OCT. 1-31, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AMERICAN ELECTRICIAN'S HANDBOOK.

By Terrell Croft. Second edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 823 pp., illus., 7 x 4 in., fabrikoid. $4.00.

A collection of the information needed by wiremen, contractors, linemen, small plant superintendents, operators and construction engineers, in selecting and installing and operating commercial electrical apparatus for the performance of various duties. This edition has been carefully revised throughout, obsolete matter discarded, new matter added and many parts rewritten.

ELECTRICAL TRANSMISSION OF PHOTOGRAPHS.

By Marcus J. Martin. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. 136 pp., illus., diagrs., 7 x 5 in., cloth, $2.00.

A brief description of the various systems devised for the transmission of photographs over metallic conductors, and of the principles underlying them. Chapters on television and on the wireless transmission of photographs are added, as is also one containing full working drawings for an experimental transmitting or receiving machine.

FIRST PRINCIPLES OF ELECTRICAL TRANSMISSION OF ENERGY.

By W. M. Thornton. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Technical primer series.) 116 pp., diagrs., 6 x 4 in., cloth. $.85.

This book is the substance of a course of six lectures given to an audience of practical engineers and students. The subject is presented from the viewpoint of the electron, not yet usual in engineering literature.

MODERN CENTRAL STATIONS.

By Charles W. Marshall. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Technical primer series.) 115 pp., illus., 6 x 4 in., cloth. $.85.

A brief description of the principal features of British central station practise, intended for young engineers. Includes the coal and ash handling plant, boiler house, engine room, switch and protective gear, plant operation and testing.

BERICHTER UND ABHANDLUNGEN DER WISSENSCHAFTLICHEN GESELLSCHAFT FUR LUFTFAHRT. (Beihefte zur "Zeitschrift Flugtechnik und Motor luftschiffahrt.") 4. Heft, April 1921. Munchen, R. Oldenbourg. 81 pp., illus., 12 x 9 in., paper. 32 M.

This supplement contains the proceedings of the sixth meeting of the Society, at Charlottenburg, 15 October, 1920. In addition to the official actions of the meeting, it contains the technical papers presented, which treat of the relation between the design of power plants for aircraft and safety in flight. The results of research in aerology and atmospheric electricity by flights, the formation of eddies by planes and advances in space telegraphy and telephony.

GESUNDHEITS-INGENIEUR.

Festnummer, Juli 1921. Munchen, R. Oldenbourg. 52 pp., 13 x 10 in., paper. 10 M.

This "Festnummer" was issued to commemorate the tenth convention of heating and ventilating engineers, at Munich in July, 1921. Papers on the heating and ventilating plant of the new Rathaus at Barmen, methods of utilizing waste heat, the development of electric heating in Switzerland and an extensive system of central heating are included, together with others on the general subject.

TEMPERATURE INDICATING AND CONTROLLING SYSTEMS.

By Franklin D. Jones. First edition. N. Y., Industrial Press, 1921. 59 pp., illus., 9 x 6 in., paper. $.50.

A general review of the application of thermoelectric pyrometers to the heat treatment of steel parts. The methods and apparatus used in various plants to indicate, control and record temperature are described and illustrated.

GENERAL PHYSICS.

By Ervin S. Ferry. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 732 pp., illus., 8 x 5 in., cloth. $4.00.

This book is designed for those students who require a coordinated elementary course in the fundamental principles, the methods and the industrial applications of physics in the early part of their college career. The laws selected for inclusion in the text are those that occur frequently in the ordinary affairs of life and those widely applied in the arts. Hypotheses still in controversy are omitted, and only simple mathematics is used.

WITHIN THE ATOM.

By John Mills. N. Y., D. Van Nostrand Co., 1921. 215 pp., illus., 8 x 5 in., cloth. $2.00.

This volume is intended for readers who wish to obtain a familiarity with the basis of modern physical science. Without mathematical formulation it deals with modern theories as to matter and energy, emphasizing the granular structure and electrical nature of matter, and the apparently corpuscular character of energy. The reader need have no previous knowledge of electricity, mechanics or chemistry.

MECHANICS.

By James E. Boyd. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 417 pp., diagrs., 9 x 6 in., cloth. $3.50.

Intended to give a working knowledge of the principles of mechanics and to supply a foundation upon which intelligent study of the strength of materials, stresses in structures, machine design and other more technical courses may rest. In the development of the subject, emphasis is put upon the physical character of the ideas expressed.

ANALYTICAL MECHANICS FOR ENGINEERS.

By Fred B. Seely and Newton E. Ensign. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1921. 486 pp., diagrs., 9 x 6 in., cloth. $4.00.

The aim in this book has been to make the principles of mechanics stand out clearly, to build them up as much as possible from common experience, to apply the principles to concrete problems of practical value, and to emphasize the physical rather than the mathematical interpretation of them. Statics, kinematics and kinetics are included, the two latter being developed with regard for the increasing importance of dynamics to engineers. The treatment of kinetics has been restricted to the more common types of motion found in engineering practise, but these motions have been treated more fully than is usual in elementary texts.

DRAWING ROOM PRACTISE.

By Frank A. Stanley. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 253 pp., illus., 9 x 6 in., cloth. $2.50.

This book deals with the making of drawings, from the simplest constructions to complete assembly and working drawings of various classes. It is based on experience in a number of leading American and European drawing rooms, and in teaching students. The difficulty in visualizing the work represented by a drawing, which many students undergo, has led the author to present photographs of the objects represented by the working drawings discussed in the book.

LESSONS IN LETTERING. BOOK 1.

By Thomas E. French and William D. Trumbull. 40 pp., 6 x 9 in., illus., paper. $.35.

The first volume of this series is devoted to the letter commercially known as Gothic, and widely used by engineering draftsmen. A series of graded exercises is given.

STEAM BOILERS.

By Terrell Croft. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 412 pp., illus., 8 x 6 in., cloth. $4.00.

This book has been compiled for men of little schooling who wish to inform themselves about the construction and operation of steam boilers, especially those preparing for examinations for engineers' licenses. It treats of the functions, history and modern types of boilers, boiler construction, accessories, steam generation, superheating, fuels, settings, furnaces, feed-waters, boiler-room equipment, inspection and management, in clear, simple language.

PNEUMATIC CONVEYING.

By E. G. Phillips. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Technical primer series.) 108 pp., illus., 6 x 4 in., cloth. $.85.

A general survey of the information available on machinery and methods for handling coal, ashes, grain and other heavy solids, with brief references to air-lift pumping, vacuum cleaning, etc.

MODERN BUILDING SUPERINTENDENCE AND THE WRITING OF SPECIFICATIONS.

By David B. Emerson. N. Y., Charles Scribner's Sons, 1921. 247 pp., 7 x 4 in., cloth. $1.75.

This volume is intended to aid the young engineer in superintending construction and in writing building specifications. The author outlines, step by step, the duties of the superintendent during the erection of a typical modern twenty-story office building, calling attention to the matters that must be watched. In similar fashion, he outlines the proper procedure in writing specifications for a small dwelling.

TIME STUDY AND JOB ANALYSIS.

By William O. Lichtner. N. Y., Ronald Press Co., 1921. 397 pp., illus., 9 x 6 in., cloth. $6.00.

The author attempts to explain the practical application of these methods in simple, non-technical terms, as might be done in a series of conferences with an executive charged with the responsibility of decision. The book first presents a general review of the principles of job standardization and their application to time study and job analysis. The organization of a staff to carry out the work is then described in detail. This is followed by a detailed description of the technique of the subject, and the book closes with a consideration of the relation of job standardization to industrial problems.

THE PSYCHOLOGY OF INDUSTRY.

By James Drever. N. Y., E. P. Dutton & Co., 1921. 148 pp., 8 x 5 in., cloth. $2.50.

Dr. Drever discusses such topics as the intelligence and vocational fitness of the worker, scientific mental engineering, the factors determining efficiency of work, fatigue, economy of movement, advertising and salesmanship. Upon these and similar matters he sets forth what has been done by the psychologist, in language understandable by the ordinary man. A special effort is made to adhere to the psychological point of view and to emphasize principles rather than details of results.

COMMERCIAL COMMODITIES.

By Frank Matthews. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. 319 pp., illus., 9 x 6 in., cloth. $4.00.

The purpose of this book is to give a not too detailed idea of the important raw or semi-manufactured articles used in trade. A wide variety of materials is described, including the mineral and metallurgical products, foodstuffs, drugs, textiles, oils and fats, plant juices, etc.

ECONOMIC ASPECTS OF THE GREAT LAKES—ST. LAWRENCE SHIP CHANNEL.

By Roy S. MacElwee, Alfred H. Ritter. N. Y., The Ronald Press Co., 1921. 291 pp., maps, tables, 9 x 6 in., cloth. $4.00.

This work is a study of the local and national advantages to be gained from opening the Great Lakes to ocean traffic. It attempts to coordinate the information on the commercial and economic aspects of the proposed ship channel, as presented at the hearings held throughout the country by the International Joint Commission and to present the vital facts affecting the advisability of the construction of the proposed improvement.

INDUSTRIAL AND POWER ALCOHOL.

By R. C. Farmer. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921 (Technical primer series.) 110 pp., diagrs., 6 x 4 in., cloth. $.85.

This is a brief, non-technical account of the important uses of alcohol, other than as a beverage, suited to the needs of engineers requiring a handy survey of the subject.

SECTION AND BRANCH MEETINGS

PAST SECTION MEETINGS

Akron.—October 28, 1921. Preparatory to the inspection of the Laboratory of the Engineering Department of the Municipal University of Akron, short addresses were made by several members of the faculty. A trip was then made through the Laboratory and the various pieces of apparatus demonstrated by the students. Attendance 60.

Altanta.—October 27, 1921, Chamber of Commerce Building. Dr. J. W. Landrum, assisted by Dr. Allen H. Bunce, both X-Ray experts of Atlanta, gave a very interesting illustrated lecture on the use of X-Ray, diagnosis and treatment of diseases. Mr. Ralph W. Fitting, a visiting engineer from New York City, gave a very instructive talk on the use of radium and its application to diseases. A moving picture, exhibiting the various stages in the manufacture of X-Ray apparatus and also fluoroscopic picture of the bones of the human body, was shown. Attendance 125.

Baltimore.—October 7, 1921, Engineers Club of Baltimore. Joint meeting of Baltimore Sections of A. S. M. E. and A. I. E. E., and the Engineers Club of Baltimore, preceded by a dinner. Paper: "The Application of Electricity to the Drive of Merchant Ships." Speaker: Mr. E. D. Dickinson, of the Marine Department, General Electric Company. Mr. W. C. Watson also presented a paper dealing with the equipment on the new electrically driven battleship *Maryland*. A number of pictures showing the details of the equipment used in connection with the electric drive of merchant ships and in connection with the drive of the battleships *New Mexico* and *Maryland*, were shown. Both papers were discussed by Commander J. O. Fisher and Commander Miles A. Libbey. Attendance 150.

Boston.—October 28, 1921, Engineers Club of Boston. Subject: "Telephone Transmission Between Cuba and Catalina." Speaker: Mr. H. S. Osborne, of the American Telephone & Telegraph Company. Mr. Osborne spoke of the details of telephone transmission over long distances and showed the various long-distance circuits available in the United States. The particular interest of the evening was a description of the complete circuit as indicated by the title, transmissions being affected under water by cable from Havana to Key West, then over the transcontinental line, and the final link completed by radio from Los Angeles to Avalon. Attendance 100.

Chicago.—October 26, 1921, Fullerton Hall. Joint meeting with the Western Society of Engineers. Subject: "The Frontiers of the Universe—An Evening with the Stars." Speaker: Professor F. R. Moulton, of the University of Chicago. The talk was illustrated with lantern slides. Attendance over 500.

Cincinnati.—October 13, 1921, Assembly Hall, Union Gas & Electric Co. A paper was read on the subject of "Analysis of Economic Losses Due to Poor Power Factor and Basic Meterable Factors" by Messrs. J. F. Doran, J. B. Hodtum and R. C. Fryer. The kv-a. meter was explained by D. G. Angus. An elaborate demonstration was made by measuring loads at different power factors. It was also shown how power factor could be corrected by synchronous machines if properly adjusted. Attendance 70.

November 10, 1921, Assembly Hall, Union Gas & Electric Co. Subject: "Street Lighting." Speaker: Mr. L. A. Anderson, of Nela Park, Cleveland. The subject was illustrated with lantern slides. Attendance 50.

Cleveland.—October 18, 1921, Elec. League Rooms. Paper "The Lead Storage Battery and Its Application to the Automotive Starting and Lighting Field." Speaker: Mr. T. R. Cook, of the Westinghouse Union Battery Co. The speaker outlined the particular problems encountered and explained the reason for various details of design. Attendance 83.

Connecticut.—October 25, 1921, Dunham Laboratory, Yale University. Subject: "The Status and Meaning of Superpower." Speaker: Professor L. P. Breckenridge, of Yale University. The speaker expected that the report of the Superpower Commission would be ready by November 1, and that it would point to a possible saving of $250,000,000 a year through the conservation of some 50,000,000 tons of coal, the area considered being the North Atlantic Seaboard. To effect such a saving, there is proposed a scheme of utilizing highly efficient steam and hydroelectric stations to develop the bulk of the energy requirements of the area, transmitting the same by high-voltage lines to the present electric utilities and railroads for local distribution. Mr. Sidney Withington, Electrical Engineer of the N. Y. N. H. & H. R. R. drew a comparison of the various methods of utilizing electrical energy for traction purposes. All the American practise was included, especial emphasis being laid on the three-wire single-phase system perfected by the local railroad. The talk was illustrated by slides. A striking example of the rapid growth of the electric power, industry was brought out by Mr. H. R. Westcott, of Westcott & Mapes, consulting engineers. The widely different requirements imposed upon the power plants of electric public utilities and of industrial plants were contrasted by Mr. P. L. Smith, Plant Engineer of the Winchester Repeating Arms Company. Attendance 80.

Denver.—October 22, 1921, Gas & Electric Building. Subject: "Industrial Heating by Electricity." Speaker: Mr. H. Fulwider. The talk was illustrated by lantern slides, showing many of the uses to which heating by electricity is put in all kinds of industries. Attendance 28.

November 2, 1921, Denver Gas & Electric Building. Subject: "Manufacture and Application of Arc Welding Electrodes." Speaker: Mr. Charles A. McCune. The talk was illustrated by moving pictures. Attendance 54.

Detroit-Ann Arbor.—October 14, 1921, Detroit Board of Commerce. The meeting was preceded by the annual Fall dinner. Subject: "Affiliation of Technical Societies of Detroit." Speaker: Mr. A. A. Meyer. The progress of the Affiliation to date was reviewed, and some of the broader aspects of such a society, and the advantage to the A. I. E.E. of belonging, were brought out. Attendance 36.

Fort Wayne.—October 27, 1921, Decatur, Indiana. The meeting included an inspection trip through the Holland-St. Louis Sugar Company's factory. The members assembled at the Interurban Station at 5:30 and boarded a special car which had been provided through the courtesy of the Indiana Service Corporation, the members being the guests of Mr. S. W. Greenland while en route. Supper was served at the Hotel Murray about 6:45, where the Section was welcomed to Decatur by officials of the Sugar Company. After supper Messrs. Carmody and Simpson, of the Company, spoke briefly on the specific problems of the local industry, the most troublesome one being the disposal of certain refuse which has heretofore caused considerable concern in Fort Wayne by contamination of the water of the St. Mary's river. These men strongly emphasized the point that the most modern apparatus obtainable has been installed which will effectively remedy this situation. After this preliminary meeting the members were taken through the factory in small groups and explained in detail the process of extracting sugar from beets, and the operations from washing

the raw beet to sacking the refined product were observed. Attendance 71.

Kansas City.—October 21, 1921. Subject: "Storage Batteries." Speaker: Mr. William Beck, of the Engine Electric Storage Battery. Attendance 23.

Los Angeles.—October 25, 1921, Polytechnic High School Auditorium. Subject: "The Industrial West." Speaker: Mr. Robert Sibley, Vice-President of the Pacific Geographical Division. The talk was illustrated by lantern slides showing the various uses to which electric power is now put, and numerous figures were presented showing to how much greater extent electricity was used per capita in the eleven western states than in the rest of the country. Attendance 85.

Madison.—November 9, 1921, Engineering Building, University of Wisconsin. Paper: "Illustrated Description of the Lakeside Power Plant of the Milwaukee Electric Railway and Light Company at Milwaukee." Speaker: Mr. G. G. Post, Electrical Engineer of the Company. Attendance 65.

Milwaukee.—October 19, 1921, Milwaukee Athletic Club. Paper: "Industrial Labor and Employment Situation." Speaker: Professor John R. Commons, University of Wisconsin. Attendance approximately 100.

Minnesota.—October 24, 1921, Auditorium of Chemistry Building, State University, Minneapolis. Paper: "Theory of Relativity." Author: Professor W. F. G. Swann, Department of Physics, University of Minnesota. The paper was illustrated with numerous models and sketches. Attendance 225.

New York.—November 14, 1921. A joint meeting of the Metropolitan Sections of the four national societies of Civil, Mining, Mechanical and Electrical Engineers was held at Institute headquarters on the evening of November 14. The subject under discussion was "The Great Lakes-St. Lawrence Ship Canal and Power Project." Dr. W. L. Saunders opened the meeting and read a letter from Chas. T. Gwynne of the Chamber of Commerce of New York asking for a second meeting at which the opposition to the project could be presented. Dr. Saunders then referred his invitation to Gov. Miller of New York and others to attend and present their side. He then introduced Julius Barnes of Duluth, formerly U. S. wheat director, who took charge of the meeting. He outlined at length the various engineering and economic features of the entire project. Mr. Barnes then introduced H. I. Harriman of Boston, Chairman of the Massachusetts State Commission on Foreign and Domestic Commerce. Mr. Harriman devoted his talk chiefly to the question of the expense involved in building and operating the canal and showed that the proposed hydroelectric development in connection with the large dam to be constructed near Cornwall would provide for the generation of 1,700,000 h. p., the income from the sale of which would over balance fixed charges, operating and maintenance expenses. He also outlined the effect of the canal on foreign and domestic commerce and on the cost of wheat and other exports.

Gov. Allen of Kansas followed Mr. Harriman and covered the subject from the viewpoint of the sixteen states of the middle west most interested in obtaining the canal for the export of their food products direct in ocean going ships. He stated that the saving on wheat alone at 5 cents per bushel during the past year could have paid for the entire project. Gov. Allen then took the objections advanced by Gov. Miller in a speech at Buffalo and answered them individually, pointing out the extremely congested condition of the various seaports and the relief which the canal would bring.

Former Gov. Harding of Iowa followed Governor Allen and was in turn followed by Dr. McElwee of Georgetown University, formerly director of the Bureau of Foreign and Domestic Commerce.

Panama.—October 23, 1921, All America Cables Building. Paper: "The Submarine Cable." Authors: Messrs. M. L. Cordua and H. Pescod. Attendance 52.

Philadelphia.—October 10, 1921. The meeting was preceded by a dinner at the Engineers' Club. Subject: "Military Intelligence." Speaker: Major J. S. Stewart-Richardson. Attendance 76.

Portland.—October 12, 1921, University Club. Subject: "What is Relativity." Speaker: Professor A. A. Knowlton, Department of Physics, Reed College. The speaker held the keenest attention of the audience for over an hour with a very interesting and vivid explanation of the fundamentals of the Einstein Theory of Relativity. Attendance 100.

Providence.—November 4, 1921, Providence Engineering Societies Rooms. Subject: "Manufacture of Insulated Wire and Cable." Speaker: Mr. W. I. Middleton, Electrical Engineer for the Simplex Wire and Cable Co. The talk was very well illustrated with slides covering all the processes and machines used in applying the insulation and protective coverings and in the making of cable. Attendance 75.

Rochester.—October 28, 1921. Subject: "State Licensing of Professional Engineers." Speaker: Mr. Virgil S. Palmer, Industrial Engineer of the Eastman Kodak Company. The speaker gave a very interesting talk on the history, work and purpose of the New York State License Law, going fully into the details of the law, giving definitions and application of the law. His talk covered the subject of licensing of professional engineers very thoroughly and was greatly enjoyed by those present.

St. Louis.—September 28, 1921, Engineers Club. Subject: "The Relation of the Institute and the Student Branch." Speaker: Professor W. L. Upson, of Washington University. The meeting was concluded with motion pictures of Grand Canyon giving some idea of the proposed enormous water power possibilities in this district. Attendance 40.

October 26, 1921, Century Electric Company. The entire membership of the Associated Engineering Societies was invited to be the guests of the St. Louis Section of the A. I. E. E. Subject: "The Automatic Start Polyphase Induction Motor." Speaker: Mr. J. L. Hamilton, Chief Engineer, Century Electric Company. Attendance 210.

San Francisco.—September 23, 1921, Engineers' Club. Subjects: "Rates of Electricity in Mining Districts" by Mr. R. E. Fisher; "How Operation About a Mine or Metallurgical Plant Can be Scheduled to Fit a Power Contract" by Mr. B. B. Beckett; "Application of Electricity to Mining and Milling at the Alaska Gastineau Plant" by Mr. B. L. Phane; "Prevention of Accidents in Mining Operation" by Mr. R. L. Eltringham. Attendance 80.

Schenectady.—October 13, 1921, Edison Club Hall. Special joint meeting of Schenectady Section A. I. E. E., Schenectady Board of Trade, Eastern New York Section A. S. M. E. and Society of Engineers of Eastern New York. Subject: "Pressing Industrial Problems." Speaker: Mr. Magnus W. Alexander. Managing Director of the National Industrial Conference Board. Attendance 175.

October 21, 1921, Edison Club Hall. Subject: "Third Harmonics in Transformers." Speaker: Mr. G. Faccioli, of the Pittsfield Works, General Electric Company. The speaker described the distortions in the electromotive force and current waves that may occur in case of certain types of connections in single-phase transformers, when connected in a three-phase bank, and in the case of three-phase transformers of shell-type construction. He described how these distortions were the result of third and higher harmonics, but principally third harmonics. These harmonics are the natural result of the magnetic properties of iron. Mr. Faccioli showed to what extent it is possible for the potential to rise as a result of this third har-

monic phenomena; and how these excessive potential conditions are often aggravated by connecting the transformer bank to a high-tension transmission line. In closing, the speaker explained how these excessive potentials resulting from third harmonics, can be converted into harmless third harmonic Currents by the simple expedient of using such types of transformer connections or so connecting the neutrals of generators and transformers, or the neutral of one bank of transformers with that or another suitable bank in such manner as will permit the flow of third harmonic current. Attendance 200.

Seattle.—October 18, 1921, Commercial Club Rooms, Tacoma, Wash. Subject: "The Economic Side of Engineering Plans." Speaker: Professor William A. Russell, of the University of Washington. The speaker said in part that the moment an engineer passes out of the cycle of his earliest work devoted to (a) questions of absolute cost, and (b) relative cost of projected construction, and enters the domain of planning work proper, embracing as this does the question of revenues, he is placed face to face with the economic problem of values, of utility, of human wants, needs and desires. During the last twenty years production has been rapidly catching up with the so-called recognized demand, and the attention of the industrial world is turning towards satisfaction of the latent demands of humanity; this fact being shown by the advent of industrial engineers, management engineers, etc. The planning engineer is turning more from questions of cost and profit to problems of eventual benefit to society as a whole. As isolated units many engineers are giving their efforts to problems of national economics, as witnessed by the acceptance of a cabinet post by Mr. Herbert Hoover. But collective activity on the part of the organized engineers of this country in "engineeringly" planning the economic future of humanity is still in its infancy about the only conspicuous instance being the report on causes of economic wastes prepared by the American Engineering Council. The systematic study of economic problems and their solution by engineering methods of approach must be recognized as a basic function of all engineering associations. Attendance 40.

Spokane.—October 28, 1921, Davenport Hotel. Subject: "Intake Works of the Spokane Upper Falls Station." Speaker: Mr. L. J. Pospisil. Attendance 18.

Toronto.—October 14, 1921, Engineers' Club. Social Evening and Get-Together Meeting. The meeting was opened by an address on the Aims and Activities of the Institute by Mr. W. F. Wright, followed by a brief talk on the privileges of membership by Mr. W. Amos. The program consisted in orchestral and vocal selections interspersed with instrumental solos, together with talks on current topics by members of the Section. Light refreshments were served, and an excellent opportunity given for old and new members to become better acquainted. Attendance 80.

October 28, 1921, Chemistry and Mining Building, University of Toronto. Subject: "Manufacture of Incandescent Lamps." Speaker: Mr. Brownlee, of the Sunbeam Lamp Co. The speaker stated that owing to the breadth of the subject it would be necessary that he confine his attention solely to one type, the vacuum lamp. He first called attention to the very low efficiency of even the best lamp, and stated that as every possible element has been tried for filament material, it would appear that much increased efficiency in light production can only be attained by the development of some new principle. He then gave a very instructive illustrated talk on the assembly, basing and factory tests of lamps, with particular attention to the requisites and development of filaments, tracing the development through the platinum, carbon, treated carbon, matalized filament, osmium, and tantalum to the present day tungsten filament. Details were given of the production of tungsten from the raw ore to the drawn wire, and interesting data of filament design were presented. The speaker explained the principle of the so-called "vacuum getters" whose object is to render transparent the tungsten compounds which are deposited in the interior of the bulb. Explanation was also given of the requirements of the lead-in wires, showing how they have developed from pure platinum to the present inexpensive and very efficient seals. Mr. Zay Jefferies, of Cleveland, also spoke on the matallurgical properties of the tungsten. Attendance 77.

Utah.—October 28, 1921, Commercial Club. Subject: "The Electrification of Trunk Line Railways." Speaker: Dr. J. F. Merrill, Dean of the College of Engineering of the University of Utah. Dr. Merrill reviewed the development of railway electrification up to the present time and presented valuable data as to the economies that were possible by the use of electrification. Mr. C. P. Kahler, of the Oregon Short Line R. R., followed Dr. Merrill with a paper on "Characteristics of Steam and Electric Railways." Mr. Kahler presented valuable data as to the costs of operating and maintaining steam locomotives and analyzed the questions to show under what conditions electrification is feasible and economical. Following the papers the moving picture "King of the Rails" was shown. Refreshments were served. Attendance 50.

Vancouver.—October 7, 1921, Board of Trade Auditorium. Subject: "Electric Pumping for Irrigation, Reclamation and Drainage." Speaker: Mr. G. R. Alexander, of the Byron Jackson Iron Works, San Francisco. The talk was illustrated with forty-five excellent slides. Attendance 37.

November 4, 1921, Board of Trade Auditorium. Subject: "Modern Street Lighting." Speaker: Mr. F. W. MacNeill, Sales Engineer of the Canadian General Electric Company. The talk was illustrated with fifty-one slides. Attendance 37.

Washington.—October 11, 1921, Cosmos Club Hall. Subject: "The Principles of the Radio Direction Finder." Speaker: Mr. L. E. Whittemore, Radio Section, Bureau of Standards. The subject was illustrated with lantern slides and with apparatus showing the application to Marine Navigation. Mr. D. H. Shellcross, Bureau of Engineering and Director of Naval Communications, spoke on "Naval Radio Compasses;" and Major L. B. Beudev, Signal Corps, U. S. A., on "Radio in the Army." Mr. A. Crossley, Expert Radio Aide in Charge of Research Section, Radio Division, Bureau of Engineering, Navy Department, spoke on "Radio Developments." Attendance 140.

Worcester.—October 20, 1921, E. E. Building, Worcester Polytechnic Institute. Subject: "Modern Illumination and Its Application." Speaker: Mr. James Ketch, of the National Lamp Works, Cleveland. Attendance 60.

PAST BRANCH MEETINGS

University of Arkansas.—October 14, 1921. Election of officers as follows: Chairman M. X. Ware; Vice-Chairman, J. A. Thompson; Secretary, B. R. Askew; Treasurer, L. G. Huggins. Professor W. B. Stelzner discussed Student enrolment in the A. I. E. E., and the scope of action for the Branch during the coming year. Attendance 14.

October 18, 1921. Subjects: "The Field of Engineering, dealing with its Past History and Present Possibilities" by Dean W. N. Gladson; "Electric Propulsion of Battleships as Discussed in the A. I. E. E. Journal" by J. C. Albritton. Attendance 19.

November 1, 1921. Subjects: "Outstanding Characteristics of the Modern Power Plant" by Gale Huggins; "Current Superheater Practise as Discussed in the A. S. M. E. Journal" by L. M. Jory. Attendance 16.

Armour Institute of Technology.—October 27, 1921. Subjects: "Wireless Aboard Ship" by A. R. Mehroff; "Railroad Signaling" by R. S. Kenrick. Attendance 53.

Brooklyn Polytechnic Institute.—October 14, 1921. Election of officers as follows: Chairman, Henry Ladner; Vice-

Chairman, A. E. Shaw; Secretary, O. Engstrom; Treasurer, Marvin Leibowitz. Attendance 30.

November 4, 1921. Subject: "Electrochemistry." Speaker: Dr. Caldwell, Department of Chemistry, Brooklyn Polytechnic Institute. Attendance 77.

Bucknell University.—November 7, 1921. Subject: "Manufacture of Tungsten Bulbs." Speaker: Professor Hall. Attendance 36.

University of California.—October 12, 1921. Subject: "Hydro-Electric Design and Construction." Speaker: Mr. W. P. L'Hommidieu, of the San Francisco Office of the Westinghouse Elec. & Mfg. Co. Attendance 44.

October 26, 1921. Subject: "Development of the Caribou Power Plants of the Great Western Power Company." Speaker: Mr. J. A. Koontz, Jr., of the Great Western Power Company, San Francisco. The talk was accompanied by a showing of two reels of films of the development. Attendance 42.

Carnegie Institute of Technology.—November 3, 1921. Subject "Electrification of Railroads and the Relative Advantages of Alternating-Current and Direct-Current on Railroads." Speaker: Mr. N. W. Storer, of the Westinghouse Electric & Manufacturing Company. Attendance 63.

Case School of Applied Science.— October 11, 1921. Following dinner at the Case Club, Mr. C. G. Maxwell gave a highly instructive talk on "The Utilities Industry—Its Economic Side." Attendance 46.

University of Cincinnati.—September 26, 1921. Subject: "The Working Tools of an Engineer, viz., English, Mathematics and Common Sense." Speaker: Professor A. M. Wilson. Attendance 85. (Section I.)

October 10, 1921. Subject: "The Working Tools of an Engineer, viz., English, Mathematics and Common Sense." Speaker: Professor A. M. Wilson. Attendance 72. (Section II.)

October 17, 1921. Subject: "Psychology and Personality." Speaker: Professor B. B. Breese. Attendance 80.

October 24, 1921. Subject: "The New Tesla Outfit Constructed at the University of Cincinnati." Speaker: Mr. A. B. Smedley. Attendance 82.

Clarkson College.—October 4, 1921. Election of officers as follows: Chairman, Richard L. Conboy; Secretary, Francis H. Fults; Treasurer, Clarence E. Fuites. Subject: "Some Phases of Electrical Railway Engineering." Speaker: Professor A. R. Powers. Attendance 23.

October 18, 1921. Lantern slide lecture on "The Advancement of the Electrical Industry." Films of the General Electric plants at Schenectady, N. Y., and Pittsfield, Mass., were also shown. Attendance 26.

November 1, 1921. The following General Electric Company films were shown: "Revelations of X-Ray" and "Production of Lamp Cord." Mr. Stebbins of the Western Electric Company, gave a short talk on the educational service of that Company. Attendance 22.

University of Colorado.—October 27, 1921. Mr. F. B. Doolittle gave a report on the A. I. E. E. Convention at Salt Lake City. Mr. R. E. Hieronymus gave an account of the theory and operation of the telegraphone. Attendance 35.

Iowa State College.—October 26, 1921. Regular quarterly smoker and get-acquainted meeting. Talks by the following: Professor F. A. Fish on "Essentials for Success"; Professor E. R. McKee on "College Activities"; Professor E. C. Kurtz on "The Field of Electrical Engineering"; Mr. L. D. Martin, Senior Electrical Engineering Student, on "Ames Engineers Away from Ames;" T. O. Millard, Senior Electrical Engineering Student, gave several impromptu stories from an unceasing supply; and Professor R. O. Joslyn on "Ames as an Engineering College." Music was furnished by Metcalf's orchestra. Refreshments were served. Attendance 124.

University of Kansas.—October 20, 1921. Subjects: The Keokuk Plant" by W. Anderson; "The Two-Cycle Multimotor" by C. W. Campbell; "Retracing Compass Lines in the East" by Professor Ockerblad. Attendance 56.

November 3, 1921. Subjects: "Circuit Breakers" by Mr. Schlagg; and "Electric Welding" by Mr. Covey. Further discussion of both subjects by Professor Shaad. Attendance 51.

Lehigh University.—October 13, 1921. Subjects: "Electrification of the Chicago, Milwaukee & St. Paul Railroad" by Mr. J. D. Aldrich; "Modern Developments in Electric Machinery" (illustrated) by Mr. H. G. Harvey. Attendance 41.

Lewis Institute.—November 2, 1921. Election of officers as follows: Chairman, E. Millison; Secretary-Treasurer, E. R. Lindberg. Attendance 14.

University of Maine.—October 19, 1921. Election of officers as follows: Chairman, Foster Blake; Vice-President, H. S. Dennison; Secretary, C. Roger Lappin; Treasurer, Perry Shean.

October 25, 1921. Subject: "Modern Power Plant Practise." Speaker: Mr. H. W. Smith, of the Westinghouse Electric & & Mfg. Co. Attendance 80.

Michigan Agricultural College.—October 25, 1921. Talks by the following: Professor Cory on "The Qualities to be Looked for in an Engineer"; Professor Foltz on "How to Improve Oneself"; Mr. Rayner, a senior, gave a few interesting demonstrations of high-frequency current; Mr. Kinney, of the Electrical Department, demonstrated the theory and use of the transformer; Professor Sawyer spoke on "Selecting One's Life Work." Refreshments were served. Attendance 45.

University of Michigan.—October 26, 1921. Subject: "From Legs to Motored Wheels" (illustrated). Speaker: Mr. Arthur E. Leet of the Mercury Manufacturing Company. Attendance 78.

University of Minnesota.—October 19, 1921. Subjects: "Aims and Purposes of A. I. E. E." by Mr. A. W. Wilson; "Prospects for the Graduating Engineer" by Mr. H. S. Langland; talks by Messrs. J. E. Magnusson, J. E. Sorenson and J. M. Downie; and violin solo by Mr. O. F. Heidelberger. One reel of moving pictures was also shown. Attendance 43.

University of Nebraska.—October 19, 1921. Short talks were given by Messrs. Lloyd Shildneck, Lewis S. Grandy and Merle Rainey concerning their summer's work with the Commonwealth Edison Co. of Chicago. Mr. Albert P. Strom gave an illustrated talk on the hydroelectric plants of Sweden. Attendance 30.

University of North Carolina.—November 1, 1921. Subjects: "History and Purpose of University Branch A. I. E. E." by Professor P. H. Daggett; "Work before Us this Year" by Professor J. H. Mustard; "Advice to New Men" by Professor J. E. Lear. Attendance 70.

University of Notre Dame.—October 17, 1921. Subject: "Direct-Current Motor Starting and Control." Speaker: Mr. Dooling, instructor. Attendance 28.

November 7, 1921. Subjects: "College Education for Engineers" by J. Huether; "Standardization of Electrical Symbols" by Ray Black. Attendance 30.

Ohio State University.—October 27, 1921. Talks by seniors and also by Professor Caldwell. Refreshments were served. Attendance 50.

November 10, 1921. Subject: "The Engineering of Men." Speaker: Mr. Willard Beahan, of the New York Central Lines. Attendance 300.

Oklahoma Agricultural and Mechanical College.—October 17, 1921. Professor Miller explained the purposes and benefits of the A. I. E. E. to new men. Mr. Bullen explained briefly the General Electric test at Schenectady, N. Y. Attendance 18.

University of Oklahoma.—October 20, 1921. Subjects: "Value of Illumination to Business Advertisement" by A. H. Schlechter; "Growth of Radio in the Next Few Years" by M. T. Prescott; "Practical Experience and Theory" by I. B. Watkins. Attendance 38.

Oregon Agricultural College.—October 19, 1921. Subject: "Some of the Aspects of the Commercial Field of Electrical Engineering." Speaker: Mr. William M. Hamilton, Manager of the Valley Division of the P. R. L. & P. Attendance 80.

Rensselaer Polytechnic Institute.—October 18, 1921. Remarks were made by several of the faculty on the history of the A. I. E. E., the local branch, advantages of Student enrolment and the like. Attendance 110.

October 27, 1921. Mr. Albert A. Northrop of Stone and Webster, Inc., described in a lecture well illustrated by colored slides and motion pictures, the Caribou 60,000-kw. hydroelectric development recently completed by Stone and Webster for the Great Northern Power Company. Attendance 325.

Rose Polytechnic Institute.—September 20, 1921. Get-together meeting with talk by Professor Knipmeyer on student activities. Attendance 49.

September 27, 1921. Motion pictures news films showing tests made by the General Electric Company with electrical pressures of a million volts. Attendance 49.

October 18, 1921. A report on the mechanical and electrical equipment of the T. H. I. and E. Power House. Mr. Pittman reported on the mechanical and Mr. Offut on the electrical equipment. Attendance 26.

October 26, 1921. Inspection trip to the T. H. I. and E. Power Plant. Attendance 32.

November 1, 1921. Informal talk by Professor Knipmeyer on mercury arc rectifiers in arc lighting circuits. Attendance 14.

November 8, 1921. Informal talk by Dr. Woodworth, President of Rose Polytechnic Institute, on the proper attitude of the engineering graduate in seeking employment. Attendance 22.

University of Southern California.—October 19, 1921. Subject: "Railways—Past, Present and Future." Speaker: Mr. L. S. Peterman, of the Southern California Edison Company. The talk was illustrated with slides. Attendance 37.

Stanford University.—October 6, 1921. Election of officers as follows: Chairman, Hugo Becker; Vice-Chairman, Charles Ellis; Secretary, Vernon Marquis. Attendance 25.

Syracuse University.—October 1, 1921. Election of officers as follows: Chairman, Eugene Ryan; Vice-Chairman, Robert J. Swackhomer; Secretary A. Percival Fugill. Attendance 9.

October 10, 1921. Subject: "Electric Ship Propulsion." Speaker: Mr. Minor P. Avery. Attendance 10.

October 13, 1921. Subject: "Electricity and the Automobile" Speaker: Mr. Ralph H. Baker. Attendance 7.

October 27, 1921. Subject: "Niagara Power Company, Power Plants at Niagara and Colfax Power Plant at Pittsburgh." Speaker: Mr. A. Percival Fugill. Attendance 9.

A. & M. College of Texas.—October 4, 1921. Subjects: "The Junior Electrical Engineering Student's Inspection Trip" by Mr. H. E. Schmidt; "What Leading Engineers Think of College Graduates" by Mr. R. B. Steele. Brief talks were made by Messrs. F. C. Bolton and O. B. Wootsen. Attendance 50.

October 18, 1921. Subjects: "Application of Electrical Power in Removing Coal from Mines" (taken from A. I. E. E. JOURNAL), by J. J. Myly; "A Short Discourse on the Law of Relativity" by C. R. Clark; "Show-Window Lighting" by J. J. Lang. Attendance 54.

Virginia Polytechnic Institute.—November 2, 1921. Election of officers as follows: Chairman, D. P. Minichan; Secretary-Treasurer, T. F. Cofer. Attendance 26.

University of Washington.—November 1, 1921. Subject: "Electric Heating in Tacoma." Speaker: Professor E. A. Loew. Attendance 31.

West Virginia University.—October 20, 1921. Subjects: "'Discussion of Engineering Society" by H. S. Shinn; "Multiplex Telegraphy and Telephony" by W. D. Stump; "The Automatic Reclosing Circuit Breaker" by C. M. Hill; "Electrostatic Dust Precipitator" by J. L. Hark; "The Limitation of the Stop Watch" by A. E. Lapie; "Iron Commutators" by F. Donnelly; "The Development of Magnetic Materials" by H. Chandler. Attendance 23.

November 2, 1921. Subjects: "Electric Ranges" by R. K. Park; "Report of American Railway Association" Porter; "Electropercussive Welding" Ernest; "Importance of Electricity on Automobiles" Mendelsohn; "Combatting Fires in Transformers and Oil Switches" Moffett; "Business Outlook for Electrical Men" Hutson; "Problems Involving Illumination of Signs and Signboards" J. R. Richards. Attendance 25.

ADDRESSES WANTED

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—John A. Dickie, Hotel Washburn, Waukegan, Ill.
2.—F. G. Ding, 1124 Ross Ave., Wilkinsburg, Pa.
3.—R. L. Ehmann, 4636 North St. Louis Ave., Chicago, Ill.
4.—W. J. Epps, Rua Dom Geraldo 80, Rio de Janeiro, Brazil S. A.
5.—G. Foung, Kay Sang & Co., 843 Clay St., San Francisco, Calif.
6.—H. L. Francis, F. C. Central Dominicano, Puerto Plata, Dominicano, Rep.
7.—Geo. P. Hoisington, 551 Aldine Ave., Chicago, Ill.
8.—T. J. Hodge, 612 West 137th St., New York, N. Y.
9.—Hugo Wm. Jacobson, 1402 East 63rd St., Chicago, Ill.
10.—Scott J. Kennedy, 632 East 17th St., Oakland, Calif.
11.—Howard W. Key, Russell Mfg. Co., 60 So. Forsyth St., Atlanta, Ga.
12.—Louis Kusner, Westinghouse Elec. Mfg. Co., Swdb. Engg. Dept. K-90, East Pittsburgh, Pa.
13.—G. H. Lindsey, Rosemere Apts., 2225 West 14th St., Los Angeles, Calif.
14.—Chas. C. Long, 1109 Arizona Ave., El Paso, Texas.
15.—George C. McCabe, 137 West 86th St., New York, N. Y.
16.—Harry P. Meyer, 327 East 61st St., Los Angeles, Calif.
17.—E. L. Neill, Box 401, Palo Alto, Calif.
18.—Chas. Schindler, Great Western Power Co., Crockett, Cal.
19.—E. V. Stoute, 1946 Mosher St., Baltimore, Md.
20.—R. H. Terry, 217 West Mifflin St., Marchson, Wis.
21.—Frank N. Tucker, 551 East 40th St., Chicago, Ill.
22.—T. S. Yang, Yonkers Y. M. C. A., Yonkers, N. Y.

EMPLOYMENT SERVICE BULLETIN

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL **should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* **not** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case **and forwarded to EMPLOYMENT SERVICE, as above.**

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

ENGINEER experienced in operating a fleet of motor trucks. Special experience in the cost of operation, handling of packages, etc. Application by letter. Location, New York City. X-1159.

YOUNG MAN with thorough technical training in electricity as applied to manufacture of heating units and motors. Desire a man capable of determining faults in design and manufacture of electric melting pot used on line casting machine. Position expected to expand to extent that man will be required to visit customer's plants and determine faults in pots that are not correctly operating. Also chance for man to make improvements in design or create an entirely new pot, if desirable. It is expected that work will later develop so that he will have chance to inspect and supervise the general operation of motors used on machines. Need not have any practical experience along this immediate line, but must have sufficient technical knowledge to fit him for above duties, a personality that would warrant sending him into customer's plant, and the judgment and initiative necessary to carry out the above outline. Application by letter giving full qualifications, including age, nationality, training and salary desired. Location New York. X-1234.

ENERGETIC ELECTRICAL MAN with executive, estimating and new business abilities, to take complete management of a going electrical contracting and repair business, may invest if desired. Application by letter. Location Brooklyn, N. Y. X-1241.

GRADUATE ELECTRICAL ENGINEER for research laboratory. Young man of pleasing personality. Must possess an analytical or research attitude and should also be able to present new ideas and developments in lighting to others. Work is entirely along the lines of utilization of light. Application by letter. Location, Cleveland, O. X-1265

SUPERINTENDENT for small municipal hydroelectric plant, town of about 2000 population, operating commercial and street lighting service; must have had experience in line construction work and be willing and able to assist with lineman and ground hand in maintenance and new work. Should understand generator and switchboard wiring, interior wiring, meters, etc., and be capable of taking charge of generating and distributing plant. Living in this town is comparatively inexpensive and this is good opportunity for man who desires to transport his family from city to the country. X-1291.

TRANSMISSION LINE SUPERINTENDENT. Applicant must be conversant with both theory and practise in transmission lines, 100,000-volt, three-phase, 50-cycle. Must be capable of taking entire charge of transmission system of approximately 400 miles of lines, must be familiar with both construction and operating work, and must be capable of handling native help. Reply stating age, experience, training and salary desired. Location India. X-1292.

ELECTRICAL ENGINEER capable of making electrical layouts, inteviewing clients and supervising outside installations. Application by letter only. Location, New York City. X-1325.

RECENT TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING. Qualifications for this position are that applicant must have electrical engineering degree from technical school of highest standing and must have a personality suitable to fit into and grow with organization. Practical experience is not necessary as we prefer recent graduate who has not been out of school long enough to become rusty on alternating-current theory. Application by letter stating age education. Location, New York City. X-1326.

ASSISTANT PROFESSOR IN ELECTRICAL ENGINEERING, for the second term of the school year. Work begins February 1st. Possibilities of continued appointment. Prerequisites—teaching and practical experience, character, personality and executive ability. Location, New England. X-1328.

INSTRUCTOR IN ELECTRICAL ENGINEERING for the second term of the school year. Work begins February 1st. Possibilities of continued appointment. Prerequisites—teaching and practical experience, character, personality and executive ability. Location, New England. X-1329.

RECENT M. E. & E. E. for telephone station layout and inspection of telephone apparatus. Location, New York City. X-1334.

INSTRUCTOR in automobile and motor truck operation, automobile construction and repair, and farm machinery. Permanent, full time position. Actual experience in the operation and repair of automobiles, trucks, and tractors. Application by letter stating age, education and experience. Position with correspondence school. X-1336.

ASSISTANT IN ELECTRICAL ENGINEERING DESIGN. Should be technical college graduate and should preferably have some experience in electric design, manufacture and testing, but need not necessarily be finished designer. Work will include electric and magnetic design calculations for a wide variety of devices, both a-c. and d-c., and will bring the man into close contact with both the manufacturing and the laboratory departments of our organization. Position permanent if applicant proves satisfactory and will offer opportunities for advancement. Application by letter, stating age, education and experience. X-1338.

EDITOR WANTED for well established monthly publication devoted to the stationary power plant field. Covers steam and electric engineering, refrigeration and other allied engineering subjects. Further details can be secured by correspondence and applicants should indicate in their first letter their general qualifications for such a position. X-1350.

SALES ENGINEER for manufacturer of steel transmission poles and towers; must be well educated in electrical engineering, have working knowledge of steel construction; preferably man with experience in the sale of transmission towers. Give complete information as to education, experience, salary, trade experience, references. Also, if possible, send photograph. Postion has large possibilities for right man. X-1378.

SUPERINTENDENT OF POWER STATION. Must be a man who has had at least three years charge of natural gas and Diesel engine-driven generating sets, of approximately 500 h. p. Total capacity of plant, 3000 kw. High-tension system, 19,000 volts. Engines are Westinghouse; Snow; McIntosh-Seymour. Generators G. E. Modern full improved house provided, including light and heat. X-1379.

MEN AVAILABLE

EXPERIENCED ELECTRICIAN. Substation construction, operating and armature winding; two years technical training. Age 24, single. Will go anywhere. E-3065.

GRADUATE ELECTRICAL ENGINEER, age 25, married, desires position with chance for advancement. One and one-half years experience engineering department company manufacturing physio-therapy and X-ray equipment. Experience with ultra-violet apparatus such as used in water sterilization. Familiar with recent developments in actino-therapy. E-3066.

TECHNICAL GRADUATE, age 28, with six years experience, including engineering in distribution and operating department of public service company; tests, and construction, with manufacturing companies; wishes position with public utility company or with manufacturing concern. Location immaterial. Available immediately. E-3067.

HYDROELECTRIC SWITCHBOARD OPERATORS—TWO, with technical training. Desire positions with large power company. Will go anywhere. E-3068.

MECHANICAL AND ELECTRICAL ENGINEERING GRADUATE, class 1920, age 28. Desires position in electrical engineering field or as instructor in elementary electrical engineering, physics or mathematics or as laboratory instructor in electrical engineering or physics. No teaching experience. Experienced in designing and opera-

tion of oil refining machinery, hydroelectric designing and operation and commercial fields. Prefer Pacific Island, South America or China. Employed at present. E-3069.

INDUSTRIAL ENGINEER, now Electrical Engineer of works with 1200 motors, 130 cranes, power plant, etc. Age 34, Mem. A. S. M. E., Mem. A. I. E. E., etc. $6000. E-3070.

CHIEF MINE AND MILL ELECTRICIAN, married, 25, hard worker with initiative and pep. Six years hard practical experience, two years college work, technical education mostly self attained. Capable rewinding, reconnecting motors, experienced on both alternating-current and direct current. Experience covers most up-to-the-minute electrical practises about mine and mill. Good references, Assoc. A. I. E. E. Go anywhere. Present contract expires January 1, 1922. E-3071.

TURBINE ENGINEER—M. I. T., 1912; married, 36 years of age. Nine years experience in research and technical design of steam turbines; one year on design and construction of steam electric power plants. Wants a position of a research or consulting engineer with a progressive manufacturer or public utility concern or with a concern of consulting engineers. E-3072.

GRADUATE ENGINEER (E. E.), age 31; experience, sales engineering, plant engineering, testing, distribution and transmission engineering, present work matter of confidential correspondence. Desires position in commercial or industrial engineering work (not traveling) or central station. Location, Middle West, New York or New England States. Associate A. I. E. E. E-3073.

ELECTRICAL MECHANICAL ENGINEER fourteen years experience, factory testing, engineering, commercial work, engineer and assistant superintendent of large hydrosteam power company, superintendent electric department railway electric light and power company, in electric engineering department of holding company. Age 36; married. Available immediately. Desires position as manager of electric utility. E-3074.

ELECTRICAL ENGINEER, Age 22. University of Michigan graduate. Member A. I. E. E. One year sales experience. Two years appraisal work. Desires position with company in foreign country. Location immaterial. Available after November 1st. E-3075.

ELECTRICAL AND MECHANICAL ENGINEER, age 43, open for engagement anywhere. Has over twenty-two years experience in power house construction, operation, and maintenance, also all kinds of railway work, substations etc. Low and high-tension work up to 100,000 volts. Has been in charge as superintendent for 9 years of 145,000-h. p. plant. E-3076.

EXECUTIVE ENGINEER, desires change in location. Eastern Canada or United States preferred. Proved ability along constructive and productive lines. E-3077.

TECHNICAL GRADUATE, age 27, single, 3 years experience with power company, 4 years with manufacturing concern, drafting, wiring diagramming, testing, etc. Desires position with growing concern, preferably in East but will go anywhere. E-3078.

TECHNICAL GRADUATE, with electrical and steam power plant experience and now employed as power superintendent desires change. Sales preferred. E-3079.

MECHANICAL AND POWER ENGINEER. Technical graduate, B. S. and M. E., age 30, eight years experience along broad lines, chemical, machine shop, metallurgy, sugar engineering, industrial and power plant practise, operation, design, layout, calculations, heating, distribution of steam, water, etc. Has business and executive ability. Desires responsible position. E-3080.

ELECTRICAL CONSTRUCTION ENGINEER AND SUPERINTENDENT. Age 32, technical graduate, 12 years experience on high tension pole and tower lines, substations, etc., construction and engineering. At present holding responsible position, but would like change to South, California, or foreign country. Can organize and handle men to an advantage. Member A. I. E. E. Present salary $300. Excellent references. E-3081.

YOUNG MAN, 20 years of age, desires position as laboratory assistant, or switchboard operator. Two years technical training, two years operating experience. E-3082.

ELECTRICAL ENGINEER, qualified for purchase, installation, and maintenance electromechanical equipment for large coal company. Best references present employers, whom I serve in above capacity. Under 30 but possessing genuine experience from apprentice to present position besides college education. If you want a cheap man don't waste your time or mine. E-3083.

TECHNICAL GRADUATE, INDUSTRIAL ELECTRICAL ENGINEERING, 12 years varied electrical experience in construction, operation and maintenance, four years G. E. test and office experience. Desires position as operating or maintenance engineer or assistant to electrical engineer in charge. Single, 35, minimum salary $1800. Available at once. E-3084.

SALES MANAGER, Electrical Engineer, age 40, desires position in charge of sales; central station and manufacturing experience. Excellen record. E-3085.

MANAGEMENT ENGINEER, well versed in finance, manufacture and construction, will be available about January 1st. Graduate Electrical Engineer. Experienced and capable executive. Age 30. Married. E-3086.

SELLING ENGINEER—EXECUTIVE, technical and university graduate; broad, practical, successful, business experience, notably sales. Affable, resourceful, personality. Straight thinking executive. Desires connection on selling end of well established concern where his opportunity for advancement is commensurate with results, initiative, and executive ability. Basis, salary and commission. Commercial and bank references. E-3087.

ELECTRICAL ENGINEER, recently connected with pumping machinery manufacturers as sales engineer, now available for position in sales, construction, or maintenance work. Married. Age 40. Eighteen years past experience in electrical and mechanical fields. Some designing, drafting, testing, inspection, contracting experience. Associate A. I. E. E. Master Electrician for City of N. Y. E-3088.

POWER ENGINEER OR SUPERINTENDENT, technical graduate, age 35. Member A. I. E. E. Experience covers management, operation and maintenance, steam and hydraulic plants both industrial and public utilities. Desires position where analytical and constructive ability leading to plant betterments is demanded. Middle Atlantic or Southern location preferred. Available early 1922. E-3089.

ENGINEER—EXECUTIVE. Assoc. A. I. E. E. Age 28, technical graduate 1915, experience test, design, installation, sales-engineer, d-c. and a-c. motors, control, switchboards, hoists. Thorough knowledge and experience of branch office management. Desires position as branch office manager or technical executive with reliable manufacturer. Available on short notice. Salary $3500. E-3090.

ELECTRICAL AND MECHANICAL ENGINEER, age 28, married, technical education, 7 years experience including: Inventory and appraisal of public utilities, construction, inspections and surveys. Desires position as assistant to comptroller in manufacturing concern or electrical and mechanical engineer. Assoc. A. I. E. E. Available January 1, 1922. E-3091.

SUPERINTENDENT OR SUPERVISOR for electrical instrument establishment. 14 years of practical experience in handling men. Familiar with up-to-date methods of production and designing of complicated apparatus. Assoc. A. I. E. E. Salary $3000. Available on short notice. E-3092.

I. C. S. GRADUATE. Naval radio experience, two years work in power station design, some business experience and quick to learn. Desires distribution work for public utility; prefer New England position. Age 22; single; Associate A. I. E. E. and Class B, N. E. L. A. Salary determined by responsibilities assumed. E-3093.

ELECTRICAL ENGINEER. Age 25; Assoc. A. I. E. E. Four years engineering experience in research and manufacturing. Desires connection with concern installing electric drives in ships. Available on moderate notice. E-3094.

GRADUATE ELECTRICAL ENGINEER. Age 32. Desires position with an industrial firm or railway, light and power company. Two years Westinghouse Elec. Co. Testing Department. Four years experience in construction, operation and maintenance work with an industrial and power company. Would like to get a permanent connection with opportunities for advancement. E-3095.

ELECTRICAL AND MECHANICAL ENGINEER. Cornell graduate, with several years experience in general engineering, desires permanent connection with industrial plant, engineering firm or exporter. E-3096.

ELECTRICAL ENGINEER. Age 36. Seven years experience with lighting and railway companies, in generating and distribution departments. Five years in consulting engineers office on investigations, report, plans and specifications for various engineering projects. Appraisals and statistical work for Commission cases. Desires position in engineering department of public utility company. E-3097.

INDUSTRIAL ENGINEER OR WORKS MANAGER, who is a journeyman machinist, technical graduate and is familiar with modern methods of management, desires suitable connection with manufacturing concern. Fifteen years experience. E-3098.

ELECTRICAL ENGINEER. University of Minnesota Graduate. Age 27, single. Completed a course as student engineer with Cutler Hammer Mfg. Co. Was head of experimental Laboratory with same company's New York works. Had considerable practical experience in the installation of automatic substation equipment. Was chief electrician in U. S. Navy. Desires a position in controller engineering or affiliated lines. E-3099.

YOUNG TECHNICAL GRADUATE. Two years G. E. motor test. Three years of power substation design layouts. Also competent to do electrical calculations pertaining to transmission line design. Age 23 years. Available at once. E-3100.

SALES MANAGER, at present occupying this position with perfect satisfaction to employer, desires a change. Graduate B. Sc. (McGill) electrical, 1903, additional 3 years shop apprenticeship course. Responsible factory executive 6 years, followed by 6 years sales, four of which as manager. Only position of responsibility considered. E-3101.

RESEARCH ASSISTANT. Age 27, desires position with a concern or private party requiring a man with broad training as an assistant and executive in applied scientific research. Full particulars as to ability and experience will be supplied upon request. E-3102.

TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING. B. S., Case, 1921, Student A. I. E. E., age 24, unmarried, desires position in any corporation or power company as construction and electrical engineer or any other position leading up to same. Opportunity, not immediate salary, main consideration. Available immediately, locate anywhere. E-3103.

YOUNG MAN, 22 with one year electrical technical training and five years of practical experience including research, central station and manufacturing; for the past one and a half years inspector and tester of automatic electric apparatus; would like position offering permanent location where past experience together with ambition is desired. E-3104.

ELECTRICAL ENGINEER desires work along line of electric railways or mine locomotives B. S. and E. E. degrees. One year with Pathe Freres Phon. Co., Brooklyn, N. Y.; several months with Boston Elevated Rwy. Co.; one year in testing department, Western Elec. & Mfg. Co., E. Pittsburgh, Pa. Latin-American origin; would consider South America. Associate A. I. E. E. E-3105.

SUPERINTENDENT, age 35, married. Desires position as plant or executive engineer with manufacturing or pulp concerns. Life long experience and technical training. Steam and hydroelectric construction and maintenance. Eight years experience in industrial electrification, maintenance and operation. At present power engineer for large pulp company. Salary $350. Available February 20, 1922. Assoc. A. I. E. E. E-3106.

ELECTRICAL ENGINEER, six years experience industrial plant applications and electrical department management, including steam power plants, 25,000 h. p. load. Broad experience with chemical industries, centrifugal pumping and difficult maintenance. Desires responsible position with consulting engineer or company with large electrical interests. Age 29, married, Assoc. A. I. E. E. State University graduate. E-3107.

ELECTRICAL ENGINEER—Age 25, technical graduate, 18 months G. E. test, 2 years experience in design and construction of switchboards and automatic substation equipments. Prefer automatic station work in Rocky Mountain or Pacific Coast states. E-3108.

ELECTRICAL ENGINEER—1919 Graduate desires position with firm making or selling arc-welding equipment. Experience includes both theoretical and practical work on arc welding. Location, East, preferable. Single, age 26. E-3109.

UNIVERSITY GRADUATE—age 31, married, 5 years experience on Westinghouse test, trouble work and general service wants position with electric railway, public utility, or large industrial plant. Has had experience teaching. Location Middle West. E-3110.

YOUNG MAN—23, has good technical training and initiative. Electrical engineering degree 1921 wishes position with future where advancement depends on personal ability. Manufacturing or testing desired, but others considered. E-3111.

ELECTRICAL ENGINEER—age 24, graduate, June 1921, from University of Michigan wishes position with some Power Plant in Middle West. Have had general wiring and maintenance experience. Available immediately. E-3112.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED NOVEMBER 17, 1921

ARMSTRONG, ADNA H., Electrician, Lundin Electrical Co., Boston; res., 285 Centre St., Dorchester, Mass.

BARNES, LYNN GARNSEY, Student Engineer, General Electric Co., Schenectady; res., 29 New Scotland Ave., Albany, N. Y.

BARRETT, ARTHUR CARPENTER, Combination Man, Mountain States Tel. & Tel. Company, Las Cruces, New Mexico.

BARRON, FREDERICK H., Draftsman, Adirondack Power & Light Corp., Amsterdam; res., 203 Huston St., Scotia, N. Y.

BASKIN, JOHN PIERCE, Draftsman, Georgia Railway & Power Co., 462 Electric & Gas Building, Atlanta, Ga.

CAINE, JACK F., Managing Director, English Electric Co., Ltd., 48 Milton St., London; res., Hurstleigh, Pinner, England.

D'ANDREA, MICHAEL EDWARD, Lakeside Drive, Rockville Centre, N. Y.

DOHL, ALFRED PHILLIP, Supervisor & Estimator, Electrical Construction, E. A. Koeneman Electric Co.; res., 1228 State St., East St. Louis, Ill.

EAMAN, THOMAS M., Sales Engineer, Fairbanks, Morse & Co., 594 Whitehall St., Atlanta, Ga.

ECKLES, FAYETTE BLAINE, Head of Testing Dept., Independent Electric Machinery Company; res., 1637 Chelsea Ave., Kansas City, Mo.

ELZNIC, FELIX F., Sales Manager, Charles Cory & Son, Inc., 183-187 Varick St., New York, N. Y.

FOSSATTI, P. G., Operating Engineer, Power Plant, International Paper Co., Jay, Maine.

GLASS, PAUL WINSOR, Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

GRAINGER, WILLIAM WALLACE, Robert A. Johnston Co., Milwaukee, Wis.

HAMILTON, JOHN, Power Station Supt., Hora Hora Power Station, via Tirau, Waikato, N. Z.

HARVEY, FRANK R., Chief Engineer, Taihape Borough Council Power Station, Elec. Dept., Taihape, N. I., N. Z.

HAYAKAWA, TOMINASA, Electrical Engineer, The Iwabuchi Electrical Engineering Co.; res., No. 12, 4 Chome, Iigura, Azabu-ku, Tokyo, Japan.

HIGUCHI, NAGAO, Engineer Officer, Imperial Japanese Navy; res., 605 W. 111th Street, New York, N. Y.

HOLLADAY, COLLIS HUNTINGTON, Engineer, Southern California Edison Co., 6th Floor Edison Bldg., 3rd & Broadway, Los Angeles, Cal.

HOXIE, HARVEY H., Sales Engineer, Ohio Brass Company, 907 Hobart Bldg., San Francisco, Cal.

HOYLE, BERNARD CLIFTON, Electrical Tester, General Electric Co.; res., 44 Mall St., Lynn, Mass.

HUMPHRIES, FRANKLIN R., Supervisor, Underground Dept., Philadelphia Electric Company, Philadelphia, Pa.

JOHNSON, MARTIN ARTHUR, Chief Electrician, Morris & Company, 5507 King Hill Ave., St. Joseph, Mo.

KERR, WILLIAM W., Electrical Engineer, Scottish Boiler & General Insurance Co., Ltd., Glasgow, Scotland.

KLAPHOLZ, MAURICE, Asst. to Head of Standardization Section, Engineering Dept., Edison Lamp Works, General Electric Co., Harrison; res., 454 S. Orange Ave., Newark, N. J.

LANSFORD, WILLIS R., Secretary, John Collins Co.; res., 3607 15th St., N. W., Washington, D. C.

MALKIN, LOUIS, 155 Newport Ave., Brooklyn, N. Y.

MARASIGAN, VICENTE, Electrical Engineer, Public Utility Commission; res., 441 Tennessee, Malate, Manila, P. I.

MASON, CARL D., Electrical Engineer, Argentine Light & Power Co., Argentine, Mich.

MATZ, CHARLES, Draughtsman, Northern Indiana Gas & Electric Co., 571 Hohman St., Hammond, Ind.

*McGINTY, ERNEST A., Engineer, Dept. of Electric Operation & Construction, Pacific Gas & Electric Co., San Francisco; res., 2506 Keith Ave., Berkeley, Cal.

NEVINS, ENNIS, Chief Engineer, City Water Works; res., 1141 E. Nevada St., El Paso, Texas.

NEWCOMB, HARRY FARRELL, Technical Employee, American Tel. & Tel. Company; res., 87 W. Industry St., Pittsburgh, Pa.

ORME, BASIL S., Chief Electrical Inspector, Insulation, Winding & Transformer Dept., Metropolitan-Vickers Electric Co., Trafford Park, Manchester, Eng.

QUIGLEY, DON L., Wire Chief, Central Union Telephone Company; res., 108 S. State St., Champaign, Ill.

RATHGEB, CHARLES CASPER, Superintendent of Construction, L. K. Comstock & Co., 21 E. 40th St., New York, N. Y.; Three Rivers, Que.

ROEWE, GEORGE J., Electrical Engineer, Ocean Accident & Guarantee Corp., 114 5th Ave., New York, N. Y.

SCOP, LEV, Works Manager, Messrs. John Robertson, Ltd., 79 May St., Belfast, Ireland.

SCOTT, WILLIAM, Electrical Engineer, Gore Borough Council, Power House, Gore, N. Z.

SCRIBNER, ELMER BENJAMIN, Chief Cable Tester, New York Edison Co., New York; Islip, N. Y.

SERY, RALPH JOSEPH, Superintendent of Maintenance, United Telephone Co.; res., 111 S. Green St., Monroe, Wis.

SHEA, THOMAS F., Technical Employee, American Tel. & Tel. Company; res., 7250 Kelly St., Pittsburgh, Pa.

*SILENT, HAROLD C., D. & R. Dept., American Tel. & Tel. Company, 195 Broadway, New York; res., 28 Hawthorn St., Brooklyn, N. Y.

SMITH, E. A., Superintendent of Construction & Assistant Chief Engineer, International Mercantile Marine Co., No. 1 Broadway; res., 596 Columbus Ave., New York, N. Y.

STEVENS, GEORGE C., Electrical Engineer, Caixa do Correio 205, Rio de Janeiro, Brazil, S. A.

STOWERS, ADDISON C., Technical Employee, American Tel. & Tel. Company; res., 7324 Kelley St., Pittsburgh, Pa.

TALLEY, W. E., Chief Electrician, Crescent Insulated Wire & Cable Co.; res., 1847 Greenwood Ave., Trenton, N. J.

TAYLOR, ORSON H., Electrical Superintendent The A. Bentley & Sons Company, 201-241 Belmont Ave., Toledo, Ohio.

THOMAS, GEORGE D., Chief Electrician, Nawn Contracting Company, Gilboa, N. Y.

TODD, ROBERT W., Engineer in Charge, Extra High Tension Switching Apparatus Development, Metropolitan-Vickers Electric Co., Ltd., Trafford Park, Manchester, Eng.

TOWNE, ROGER PERKINS, Inspector, Western Union Telegraph Company, 175 Congress St., Boston; res., 80 Milk St., Westboro, Mass.

WHITESELL, FRANK "E". LLOYD, New England Representative, Railway & Industrial Engineering Co., 136 Federal St., Boston, Mass.

Total 52.

*Former enrolled students.

ASSOCIATES REELECTED NOVEMBER 17, 1921

BURNS, THOMAS STEPHEN, Vice President & Treasurer, Acme Transport Company, Inc., 15-25 Whitehall St., New York; 749 Gotham St., Watertown, N. Y.

JEFFERY, RICHARD T., Asst. Engineer, Hydro-Electric Power Commission of Ontario; res., 8 Lonsdale Apts., Avenue Road, Toronto, Ont.

JOHNSTON, J. J. HUNTER, Mains Superintendent, Glasgow Corporation Tramways; res., Oakfield, Lenzie, near Glasgow, Scotland

MORPHET, FRANK K., Barnett Coal Company, Blairville, Pa.
PESTEL, ARTHUR, Designing Engineer, 557 W. 124th St., New York, N. Y.
SOARES, EUSTACE CHARLES, Electrical Engineer, Ophuls, Hill & McCreery, 112 W. 42nd St., New York, N. Y.

MEMBER REELECTED NOVEMBER 17, 1921

WOOD, FRANKLIN PORTER, Electrical Engineer, Woolfenden, Wood & Weber, 1109 Broadway, Denver, Colo.

MEMBERS ELECTED NOVEMBER 17, 1921

GRABE, CLARENCE G., Electrical Engineer, with Howard N. Eavenson & Associates, 1302 Union Arcade Bldg., Pittsburgh, Pa.
WEDMORE, EDMUND B., Director & Secretary, The British Electrical & Allied Industries Research Association, Westminster, London; res., 1 Sneath Ave., Golders Green, London, N. W., 11, Eng.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held November 14, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

HILL, HALBERT P., Vice-President & General Manager, Ophuls, Hill & McCreery Inc., New York.
McCONAHEY, WILLIAM M., Manager, Transformer Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

To Grade of Member

BALLARD, FREDERICK W., Senior Member, F. W. Ballard & Co., Cleveland, O.
JACOBUS, ROBERT F., Partner, Francisco & Jacobus, New York, N. Y.
KISHLAR, LAMAR M., Electrical Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.
MACNEILL, FRANCIS W., Sales Engineer, Canadian General Electric Co., Ltd., Vancouver, B. C.
MOON, FLOYD L., Electrical Engineer, Motor Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
SEAMAN, EDWIN H., Chief Engineer, Johnson & Higgins, New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 31, 1921.

Allen, Harry, Detroit, Mich.
Applegate, Lindsay M., Portland, Ore.
Ardiff, Robert J., Indianapolis, Ind.
Atherton, Alfred L., (Member), E. Pittsburgh, Pa.
Ball, Clarence E., Spokane, Wash.
Bassett, Clark L., Detroit, Mich.
Bealey, Walter DeV., Portland, Ore.
Bellamy, John I. S., Chicago, Ill.
Blackwell, William T., New York, N. Y.
Bliss, William J., Steubenville, Ohio
Brown, John J., Philadelphia, Pa.
Bruno, William A., New York, N. Y.
Burgess, Bert I., Peterboro, Ont.
Burkhalter, Rudolph, (Member), Trenton, N. J.
Canning, Dow V., Peterboro, Ont.
Cantrell, Willis R., Plainfield, N. J.
Card, Read H., Denmark, S. C.
Carmean, James H., Kansas City, Mo.
Casey, Harry J., Baltimore, Md.
Chewning, Voris O., Springfield, Ill.
Chitty, A. M., (Member), Everett, Wash.
Coleman, George B., San Francisco, Cal.
Connely, C. B., Schenectady, N. Y.
Cook, George C., Tacoma, Wash.
Cressman, Edward W., Seattle, Wash.
Crispell, Kenneth G., New York, N. Y.
Dahl, Otto G. C., Cambridge, Mass.
Davidson, Otto C., Jr., Iron Mountain, Mich.
De Land, Donald W., New York, N. Y.
d'Harcourt, J., Schenectady, N. Y.
Devendorf, Norman LeR., Jackson, Mich.
Dodd, Harold, (Member), Pensacola, Fla.
Dodson, Ralph E., Cincinnati, Ohio
Dunn, Caven H., Peterboro, Ont.
Dmytrow, Nestor, Jr., New York, N. Y.
Edwards, Harold S., Harlan, Ky.
Egan, John W., Akron, Ohio
Esteve, Carlos A., Wooster, Ohio
Feldman, Jacob G., Brooklyn, N. Y.
Ferguson, Frank L., New Haven, Conn.
Firket, Guillaume C., Ithaca, N. Y.
Flickinger, Floyd S., Seattle, Wash.
Flynn, John P., Toronto, Ont.
Foster, Edgar W., Brooklyn, N. Y.
Foster, James C., Rockville Centre, N. Y.
Freeman, Richard M., Walla Walla, Wash.
Gibbons, Edward J., Pittsburgh, Pa.
Glatzel, Earle D., Detroit, Mich.
Gowen, Robert F., (Member), Ossining-on-Hudson, N. Y.
Grier, Louis N., New Kensington, Pa.
Groff, William E., Easton, Pa.
Hagy, Burtis E., Philadelphia, Pa.
Haig, John McD., Toronto, Ont.
Haines, Arthur J. O., Allentown, Pa.
Hamilton, Brace H., (Member), Washington, D.C.
Hardie, Roderick C., Peterboro, Ont.
Hearn, George K., New York, N. Y.
Herr, Robert F., Philadelphia, Pa.
Hockett, William J., Ft. Wayne, Ind.
Holters, Joseph W., Norwood, Ohio
Horine, Ernest E., Cleveland, Ohio
Hurd, Harold R., Minneapolis, Minn.
Isawa, Tatsuo, Schenectady, N. Y.
Jeffrey, Arthur E., Medford, Mass.
Johnson, Louis B., Indianapolis, Ind.
Johnston, John F., Selma, N. C.
Keenan, Edwin C., New York, N. Y.
Kelly, James H., Tacoma, Wash.
Kemna, Rod H., Butte, Mont.
Kennedy, Gordon T., Chicago, Ill.
Kern, Charles L., Kansas City, Mo.
King, Horace W., New York, N. Y.
Kirlin, George, Montreal, P. Q.
Kleinschmidt, Edward E., (Member), Brooklyn, N. Y.
Kreyschmar, George G., College Place, Wash.
Lange, Harold T., St. Louis, Mo.
Lanigan, Leo P., Schenectady, N. Y.
Lauterback, Frederick J., Woodhaven, N. Y.
Lee, Frederick W., Baltimore, Md.
Lewis, Archie L., Bremerton, Wash.
Lincoln, Alden A., New Haven, Conn.
Lindsay, Russell H., Boulder, Colo.
Lloyd, Leonard R., Las Plumas, Cal.
Logan, Maxwell B., Toronto, Ont.
Loose, William H., Toronto, Ont.
Lyon, Gordon M., Peterboro, Ont.
Macauley, James E., Hartford, Conn.
Mansell, Walter H., Boston, Mass.
Mazzarella, Frank, Brooklyn, N. Y.
McFarland, Thomas C., Berkeley, Cal.
McAlpine, Duncan C., Butte, Mont.
McHugh, John A., New York, N. Y.
McKay, Richard, Spokane, Wash.
McKeehan, Louis W., (Member), New York, N.Y.
McKendrick, Ray H., New Haven, Conn.
Mertz, Ralph H., Detroit, Mich.
Meyer, Edward G., (Member), Indianapolis, Ind.
Miller, Frank D., Kansas City, Mo.
Miller, John H., Easton, Pa.
Miner, Ellsworth F., (Member), Litchfield, Conn.
Morris, Glen S., Kansas City, Mo.
Moulton, Thomas T., San Francisco, Cal.
Munro, David L., Toronto, Ont.
Nichols, Reed J., Detroit, Mich.
O'Connor, Johnson, Lynn, Mass.
Oldrey, Kenneth F., Erie, Pa.
Osgyani, Gaston L., New York, N. Y.
Parvin, Edward G., Garwood, N. J.
Penney, Lester T., Hempstead, N. Y.
Perrine, James O., (Member), New York, N. Y.
Pollock, Robert B., Los Angeles, Cal.
Pope, Mark C., Jr., Washington, D. C.
Quimby, Clifton C., (Member), Boston, Mass.
Roberts, Edwin W., Philadelphia, Pa.
Roche, George J., Bethlehem, Pa.
Roudenbush, George H., Jr., Cleveland, Ohio
Rule, Thomas W., Topeka, Kan.
Rutherford, Burton G., Peterboro, Ont.
Schmelz, Frederick C., Detroit, Mich.
Schrader, Frank J., Cedar Rapids, Iowa
Sherbine, Harry M., Detroit, Mich.
Siling, Philip F., New York, N. Y.
Simons, Donald MacL., E. Pittsburgh, Pa.
Simson, George F., Toronto, Ont.
Slane, Ambrose F., Brooklyn, N. Y.
Sloan, John H., Toronto, Ont.
Smith, Eric D., Chicago, Ill.
Smith, Harry H., Thompsonville, Conn.
Speer, George A., Niagara Falls, N. Y.
Spickard, Lenney O., Tacoma, Wash.
Squire, William J., Kansas City, Mo.
Stelle, Christopher B., South Bend, Ind.
Stewart, Henry G., Winnipeg, Man.
Stopps, Leonard G., Hamilton, Ont.
Stover, William B., Newark, N. J.
Strebig, John L., York, Pa.
Taylor, John W. R., Toronto, Ont.
Thurmond, William H., Brewster, Fla.
Tomlinson, Frederic J., Peterboro, Ont.
Towne, Cecil D., Milo, Maine
Tucker, Carlton E., Cambridge, Mass.
Turnquist, Frank A., Bloomfield, N. J.
Tuthill, John J., (Member), Urbana, Ill.
Vogt, Otto E., New York, N. Y.
Vallarta, Manuel S., Cambridge, Mass.
Van Horn, Richard H., Schenectady, N. Y.
Van Tassal, Abram, (Member), New York, N. Y.
Vollmer, Robert M., Utica, N. Y.
Walker, Glen H., Schenectady, N. Y.
Weinback, Mendel P., Columbia, Mo.
Wellwood, Arthur R., (Member), New York, N. Y
Wiegner, William K., Philadelphia, Pa.
Wild, Albert E., Toronto, Ont.
Wood, John W., (Member), Seattle, Wash.
Woodson, William C., St. Louis, Mo.
Wotier, Arthur E., New Haven, Conn.
Wright, Paul C., Cleveland, Ohio
Yale, Charles M., Hartford, Conn.
Yorton, Allison T., Detroit, Mich.
Total 159.

Foreign

Allan, Arthur, Rancagua, Chile, S. A.
Bailey, Cecil, Honolulu, T. H.
Bauer, Mamerdo C., Rancagua, Chile, S. A.
Bunster, Ferdinand H., Rancagua, Chile, S. A.
Carr, James M., Rancagua, Chile, S. A.
Chacon, Ernesto, Rancagua, Chile, S. A.
Commentz, C. J., Rancagua, Chile, S. A.
Granzow, Herman F., Rancagua, Chile, S. A.
Hayat, Shaik M., Udaipur, Meywar, Rajputana, India
Hendrickson, Leo W., Rancagua, Chile, S. A.
Higgs, Walter F., Birmingham, Eng.
Hilyer, William J., (Member), Cairo, Egypt
Ito, Masaji, Kobe, Japan
Jorgensen, Jesse J., Cristobal, C. Z.
Judson, Walter R., (Member), Santiago, Chile, S. A.
Morry, Hisagoro, Osaka, Japan
McDonald, Hugh D., Rancagua, Chile, S. A.
Nakano, K., Kobe, Japan
Noronha, Edgar F., Bombay, India
Painton, Percy R., Rio de Janeiro, Brazil, S. A.
Pigott, John A., Waitara, N. Z.
Ratcliff, Henry A., (Member), Manchester, Eng.
Ray, Rankin C., Raynagar, Darbhanya, India
Ritchie, Ernest S. H., Sydney, N. S. W.
Schofield, Robert H., (Member), London, Eng.
Wilson, Richard L., Rancagua, Chile, S. A.
Total 26.

STUDENTS ENROLLED NOVEMBER 17, 1921

13686 Merkl, Frank M., University of Alabama.
13687 Kuder, Bernard, Johns Hopkins Univ.
13688 Peters, Ralph H., Kansas State Agri. Coll.
13689 Mark, Isaac, Jr., Mass. Institute of Tech.

13690 Kost, Herbert G., Carnegie Inst. of Tech.
13691 Liebeck, George S., Worcester Poly. Inst.
13692 Nelson, Earl L., University of Illinois
13693 Cadaval, Edwards G., University of Ill.
13694 Howard, John C., University of Illinois
13695 Mason, David H., University of Illinois
13696 Davis, Waldo E., University of Illinois
13697 Niemann, Wilmont E., University of Ill.
13698 Ralph, Lindley J., University of Illinois
13699 Beechler, Arthur K., University of Illinois
13700 Behrens, William J., University of Illinois
13701 Cheaney, Thomas F., University of Ill.
13702 Conrad, Clarence L., University of Illinois
13703 Groeger, Roscoe C., University of Illinois
13704 Gulley, Sanford J., University of Illinois
13705 Hornback, Robert H., University of Ill.
13706 Kerchner, Russell M., University of Ill.
13707 Kerns, Arthur D., University of Illinois
13708 Krause, Elmer G., University of Illinois
13709 Love, John J., University of Illinois
13710 Robinson, Clyde N., University of Illinois
13711 Schmalmaack, Charles L., Univ. of Ill.
13712 Shapiro, Leo, University of Illinois
13713 Smith, Charles C., University of Illinois
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